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This study is an evaluation of the harbors of Iwakuni and Kure, Japan as possible typhoon havens. Characteristics of the harbors considered include location and accessibility, the effects of topography, wave action, and storm surge during tropical cyclone passage. Other considerations discussed are the possibilities of seeking refuge in these harbors, proceeding to other havens, or evasion at sea.

20. Abstract (continued)

Tropical cyclone tracks from 1947-1972 for the western North Pacific were analyzed to determine the probability of threat to Iwakuni and Kure.

First-hand observations by the author and conversations with local harbor authorities and mateorologists are incorporated into the conclusions.

The study verifies Kure as a safe typhoon haven and designates certain anchorages near Iwakuni as safe from the most severe conditions associated with tropical cyclones.

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AN EVALUATION OF THE HARBORS OF IWAKUNI AND KURE, JAPAN AS TYPHOON HAVENS

by

JAMES R. MANNING

DECEMBER 1975

NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY
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CONTENTS

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1. INTRODUCTION

Irrespective of their size, all ships are subject to the hazards associated with severe tropical cyclones (known by such other names as typhoons, hurricanes, willi-willies, etc.). When threatened by such a storm a timely decision regarding evasion at sea or remaining in port is required. This study examines the ports of Iwakuni and Kure, Japan and their potential as typhoon havens and presents the various options available to ship captains. Due to the close proximity of the two harbors and their interrelated options and characteristics, this study is presented, where possible, as an evaluation of the entire Iwakuni and Kure harbor region rather than separate discussions of each.

In order to classify a harbor as a safe haven or an unsafe harbor during storm passage a number of factors must be taken into consideration. For example, one must consider the characteristics of the harbor, the surrounding topography, support facilities available, wind and wave action, bottom holding quality, port congestion, and problems ships may or may not encounter during storm conditions.

2. TROPICAL CYCLONES

2.1 DESCRIPTION OF TROPICAL CYCLONES

Tropical cyclones are warm-core, non-frontal, low pressure centers which develop over tropical or subtropical waters. The development of a tropical cyclone from a weak tropical disturbance into a mature typhoon is not completely understood; however, it is known that in the initial stages they require warm sea-surface temperatures, below normal pressures, and cyclonic wind flow in the Northern Hemisphere. These conditions are normally found between 5N and 20N during the spring, summer and fall seasons. Typhoons will generally weaken and dissipate with movement over continental land masses or over cooler mid-latitude waters.

2.2 WIND CIRCULATION ASSOCIATED WITH TROPICAL CYCLONES

In the Northern Hemisphere the wind circulation associated with tropical cyclones is counterclockwise around the center, or eye. Figure 1 illustrates the typical wind pattern of a large, intense 150-kt typhoon. In Figure 1 the arrow indicates the direction of storm movement. Note that the strongest winds occur in the right semicircle with respect to movement, and for this reason the right semicircle is referred to as the "dangerous semicircle."

Figure 2 depicts the general wind field about the typical Northern Hemisphere typhoon. Note in Figure 2 the strong pressure gradients and strength of the winds in the right semicircle as compared to those in the left semicircle.

The highest winds associated with tropical cyclones have never been accurately measured; however, based on data from past storms, tropical cyclone winds may attain speeds well in

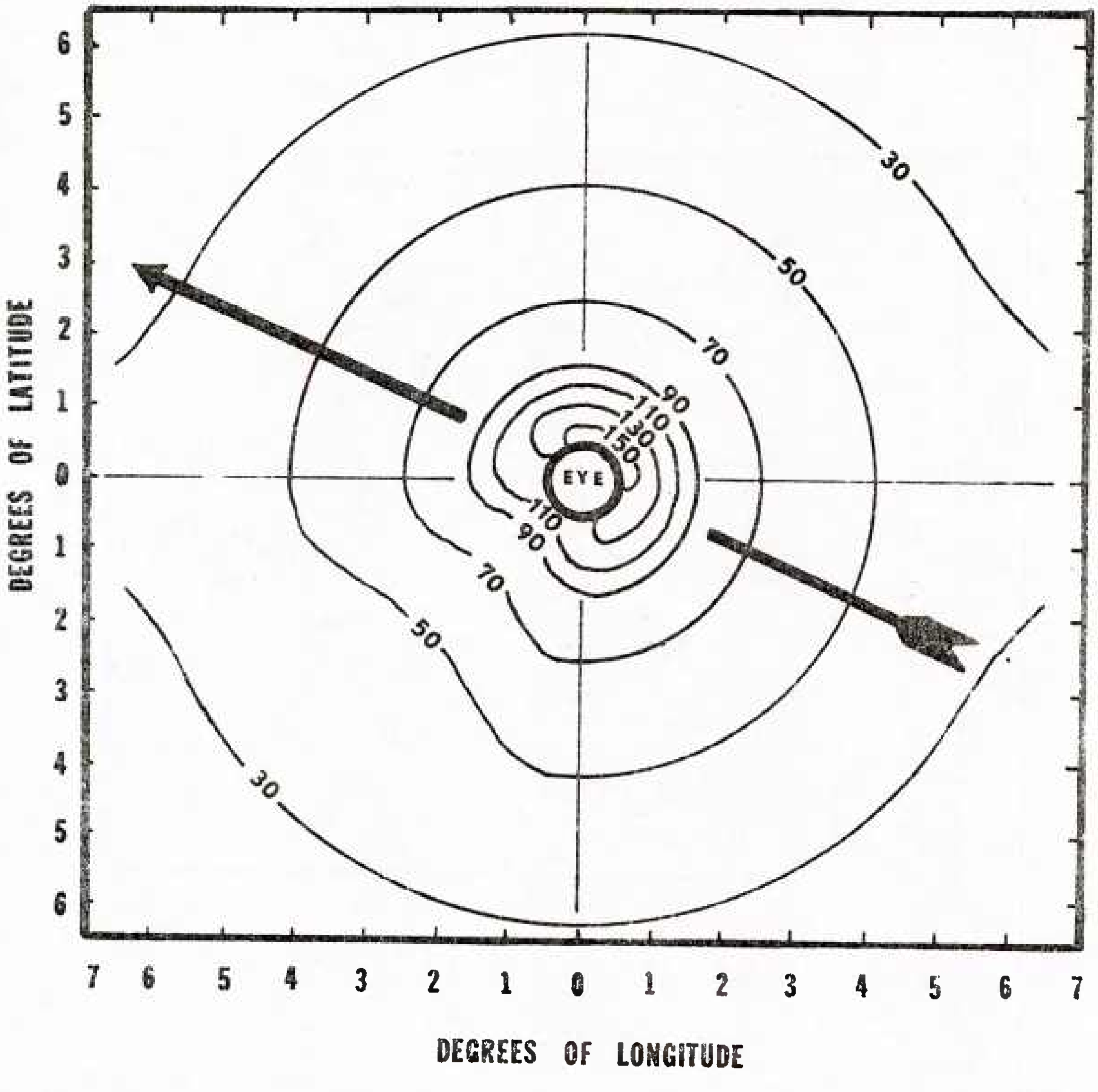

Figure 1. Distribution of surface wind speeds (in knots) around a large, intense typhoon in the Northern Hemisphere over open water. The arrow indicates direction of movement (after Harding and Kotsch, 1965).

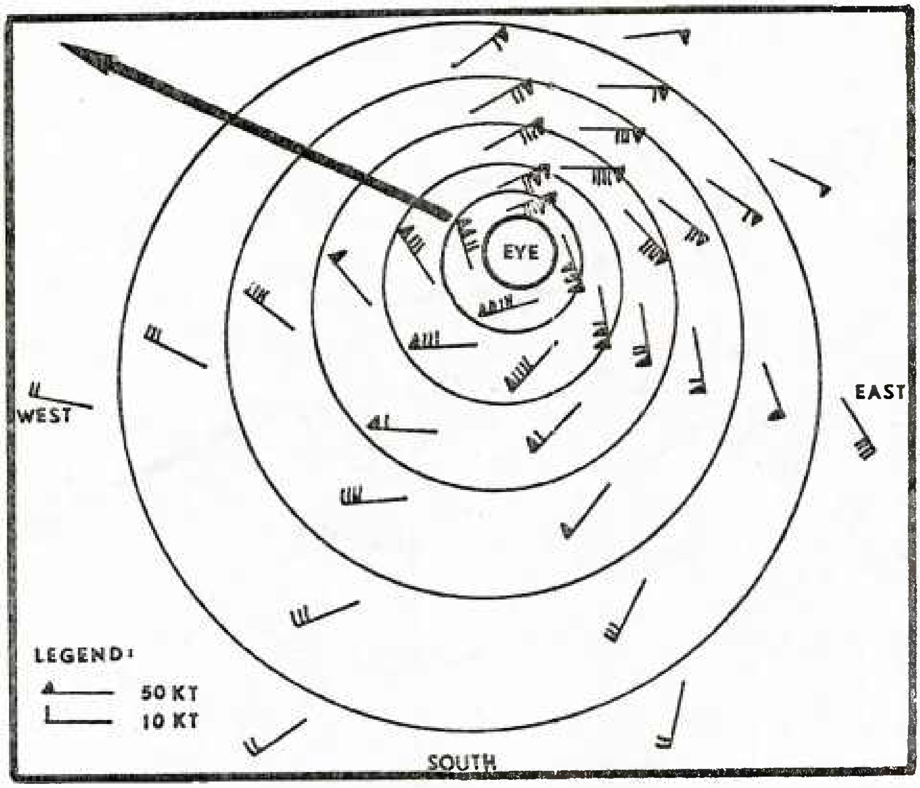

Figure 2. Distribution of surface wind speeds (in knots) around a large, intense typhoon in the Northern Hemisphere over open water. The arrow indicates direction of movement (after Harding and Kotsch, 1965).

excess of 150 kt. The following classification system concerning the intensity of tropical cyclones has been established by international agreement:

1.	Tropical Depression:	Maximum sustained winds no greater than 33 kt.
2.	Tropical Storm:	Maximum sustained winds in the range 34-63 kt.
3.	Typhoon:	Maximum sustained winds in excess of 63 kt.

Here the term tropical cyclone is used to include all three of these categories.

2.3 TROPICAL CYCLONE MOVEMENT

The majority of tropical cyclone tracks conform to a general pattern by initially moving west-northwest from their source region. Steered by the prevailing easterlies, the tropical cyclone moves at speeds from 8 to 14 kt. Normally, upon reaching latitudes between 20N-30N, tropical cyclones are influenced by the prevailing westerlies and undergo "recurvature." This implies that the west-northwest movement gradually shifts to a northeasterly direction (approximately 40% of WESTPAC tropical cyclones recurve). After recurvature, the tropical cyclone's speed of movement can accelerate within 48 hours to as much as 2 to 3 times the speed at the point of recurvature (Burroughs and Brand, 1972). However, in conjunction with the increase in speed of movement, a gradual weakening occurs as the tropical cyclone moves over cooler waters or when cool surface air enters the storm system. Figure 3 summarizes the monthly variations of the major characteristics of "recurvers" at their point of recurvature.

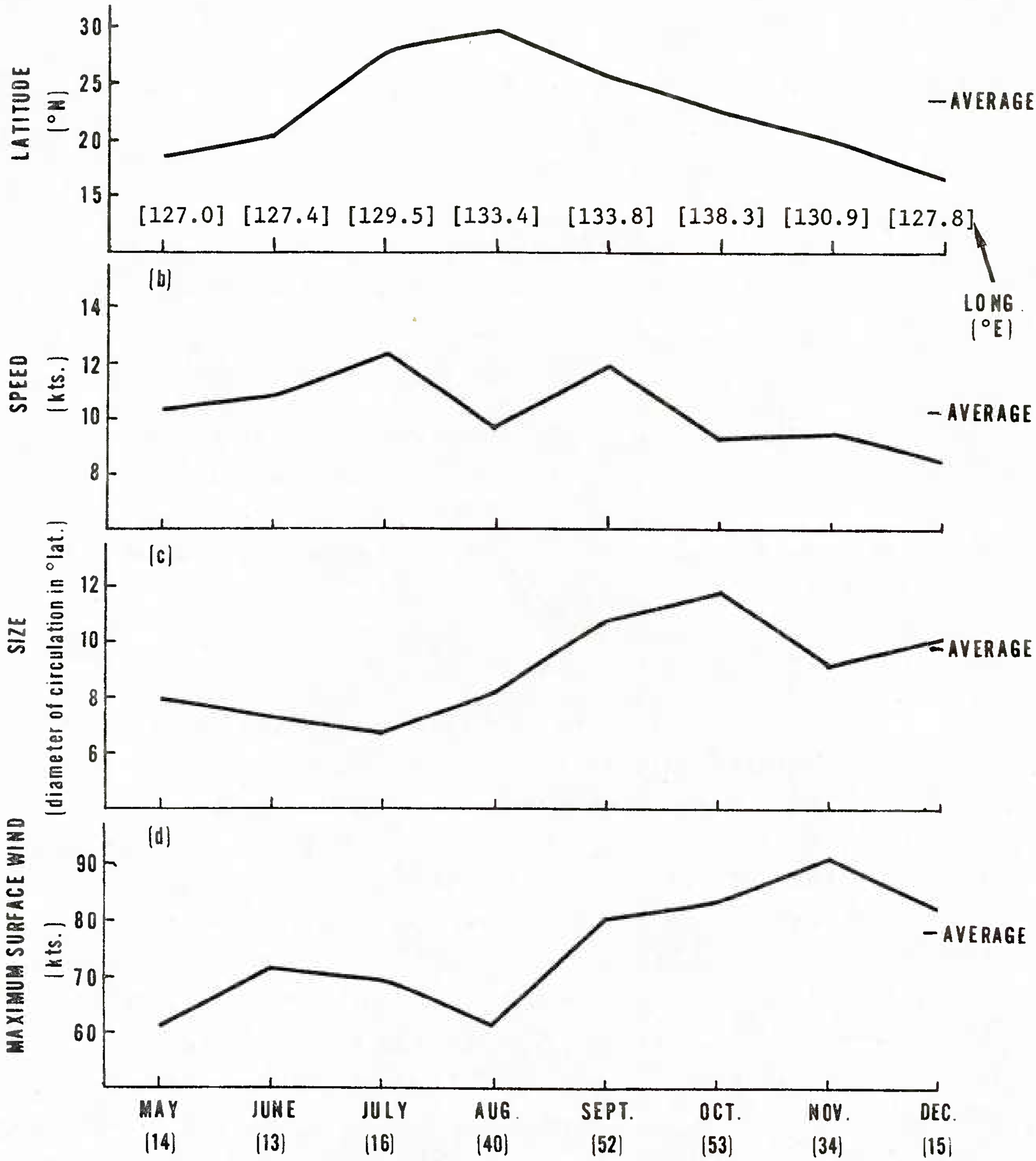

Figure 3. Seasonal variation at point of recurvature of (a) latitude and longitude [in brackets]; (b) speed of movement; (c) size; and (d) maximum surface wind for the recurving tropical storms and typhoons from May-December (1945-1969). The number in parentheses below each month is the number of recurving tropical storms and typhoons observed for each month. The size parameter is the diameter of circulation as deduced from the average diameter of the outer closed surface isobar. (From Burroughs and Brand,1972.)

Note the following in Figure 3: (1) during July-September the average recurvature point is between 25N-30N, but is further south during the other months, (2) the average speed of movement at the point of recurvature is highest during July and September, and (3) maximum surface winds and storm size are greatest at the point of recurvature during September-December.

It is important to keep in mind that the course of individual storms cannot be said to follow any standardized pattern. Numerous typhoons have followed extremely erratic courses, even making occasional loops in their tracks. For this reason, the progress of each typhoon should be closely monitored for changes in intensity, direction and speed of movement. The mean monthly typhoon tracks, track limits, and average speed of movements for the months of June-October are presented as Appendix A.

2.4 SEA STATE AROUND TROPICAL CYCLONES

It is important to realize that sea conditions affecting ship movement will extend well beyond the wind field associated with a tropical cyclone, and that a miscalculation concerning sea conditions could result in a destructive rendezvous with the storm. The extent of the sea state generated by a tropical storm is primarily a function of storm size, duration and intensity. Figure 4 shows the combined sea height[1] associated

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[1]The combined sea height is defined as the square root of the sum of the squares of "significant" sea and swell height. Sea refers to wind waves and swell consists of wind generated waves which have advanced into regions of weaker or calm winds. "Significant" will be defined here as the average height of the highest one third of the waves observed over a specified time.

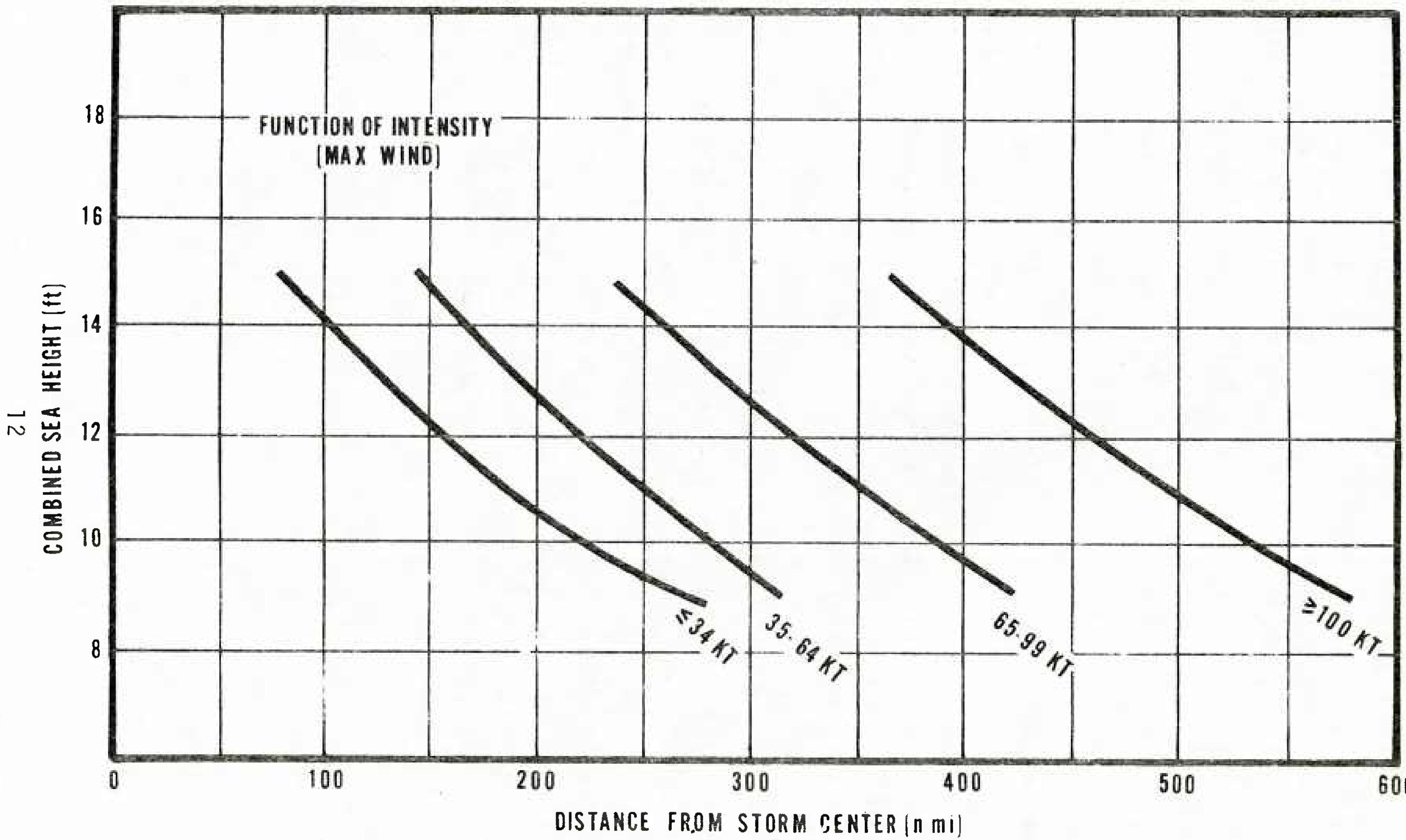

Figure 4. Combined sea height plotted against distance from storm center and given as a function of storm intensity (Brand, *et al.*, 1973).

with 21 tropical storms and typhoons (based on 173 analyses for the year 1971) plotted as a function of distance from the storm center and storm intensity (Brand, et al., 1973). Observe in Figure 4 that there is a large variation in the sea state with storm intensity. A tropical storm (winds 34-63 kt) can produce 12-ft seas or greater, within 217 nautical miles from the storm center; while an intense typhoon (winds greater than or equal to 100 kt) can produce 12-ft seas 454 nautical miles from the center. The distances given are mean distances since the isopleths (lines of equal value) of combined sea height are not symmetric about the storm center. Brand, et al. (1973), found that the actual wave heights are at least partially dependent on the direction in which the storm is moving. For example, Figure 5 shows the average combined sea-height isopleth pattern for storms moving on headings between 301° and 360° and is based on 66 sea-state analysis for tropical cyclones that occurred during 1971. Note that the greatest area of highest seas (9-15 ft range) exists to the rear and toward the right semicircle of the storm. The above figures denote average wave heights observed in tropical cyclones in the 9-15 ft range; however, a word of caution must be given in that exceptionally large waves are occasionally observed near the storm center, some of which are as high as 50-60 feet.

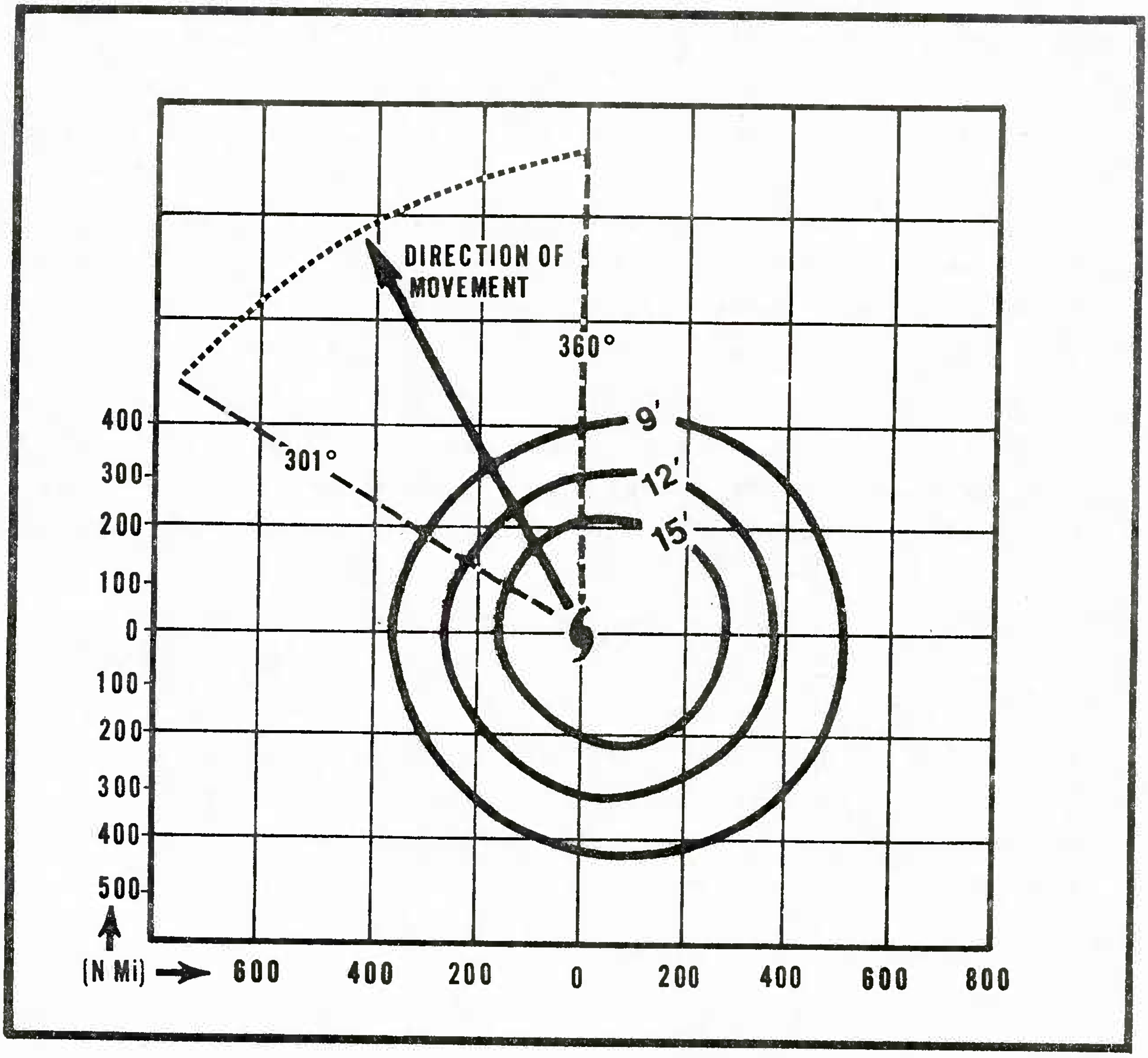

Figure 5. Combined sea-height isopleths (9-15 ft) based on 66 analyses of storms heading between 301°-360°. The mean speed of movement and mean wind speeds for these 66 analyses were 9.2 kt and 69.2 kt, respectively (after Brand, <u>et</u> <u>al</u>., 1973).

3. JAPAN

3.1 JAPANESE ISLANDS

Japan is an island nation in the western North Pacific Ocean off the eastern coast of Asia consisting of a chain extending (in an arc) from northeast to southwest. The northeastern tip is located at 46N, 143E, and the southernmost point at 26N, 131E. The four largest islands of Japan listed from north to south are Hokkaido, Honshu, Shikoku, and Kyushu. Countless smaller islands are included in the chain. Figure 6 shows the position of Japan relative to the surrounding land and water masses.

3.2 THE ISLAND OF HONSHU

Honshu is the largest of the main Japanese Islands with Iwakuni and Kure located in the southwestern region. A detailed description of Honshu and the harbors of Iwakuni and Kure can be found in the Sailing Directions (Enroute) for Japan, H.O. Pub. No. 156. For specific guidance on navigational aids and additional features in the vicinity of Iwakuni and Kure, consult Sector 11 of the above.

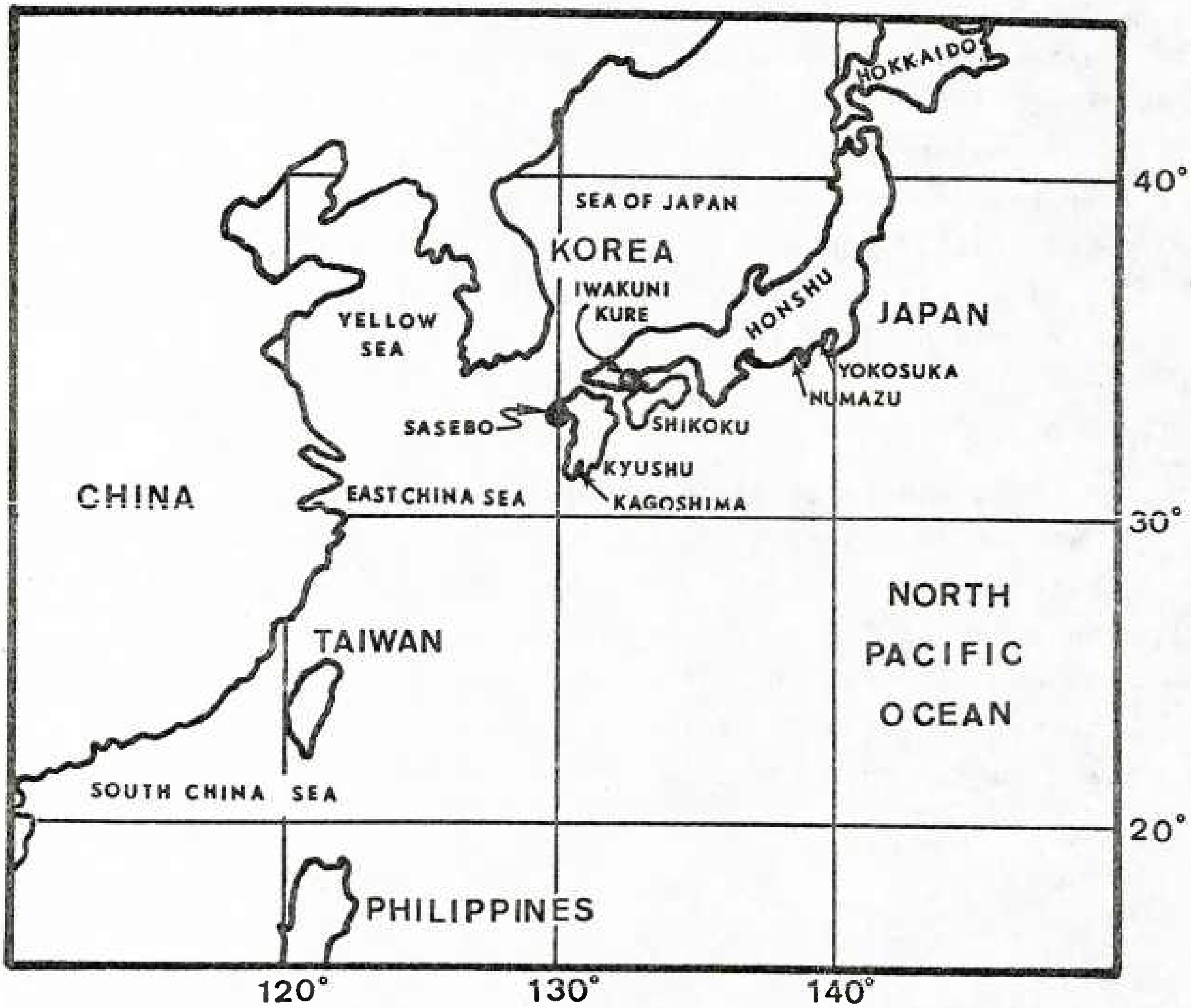

Figure 6. Locator map showing Japan and the surrounding land and water masses.

4. LOCATION AND TOPOGRAPHY OF IWAKUNI AND KURE AND THEIR EFFECTS ON TROPICAL CYCLONES

4.1 LARGE SCALE OBSERVATIONS

Figure 7 shows the relative positions of Iwakuni and Kure in Hiroshima Bay with respect to the major islands of Honshu, Kyushu, and Shikoku. Notice in Figure 7 that the mountainous terrain of these islands, with elevations exceeding 3000 ft, would lead one to expect that the winds of a tropical cyclone would be greatly reduced before reaching the Hiroshima Bay region. This is, in fact, the case when storms pass either to the west or the east of the bay region.

When storms pass to the west, the winds will normally be reduced 35-50% while storms passing to the east will usually have their winds reduced approximately 60%. Also it appears that southerly winds coming through the Bongo Straits and Inland Sea have the path of least resistance into the Hiroshima Bay area. Generally this would be the case when a storm passes to the west. Further, a very strong storm passing directly through the Bongo Straits would probably give the worst conditions in the Hiroshima Bay region.

4.2 HIROSHIMA BAY REGION

Hiroshima Bay is that portion of the Inland Sea of Japan associated with the city of Hiroshima. The area of Hiroshima Bay was covered by air mining during World War II. Channels have been swept by both U.S. and Japanese mine sweepers. Ships negotiating Hiroshima Bay should remain in the swept areas listed in the HYDROPACS and DAPAC (see H.O. 110, Sec. (6-52)-(6-61), and H.O. Chart 97267).

As seen in Figures 7 and 8, Iwakuni is located on the western side of the bay in a relatively flat, open area while Kure is embedded in a region of mountains and mountainous islands with almost complete protection from all directions.

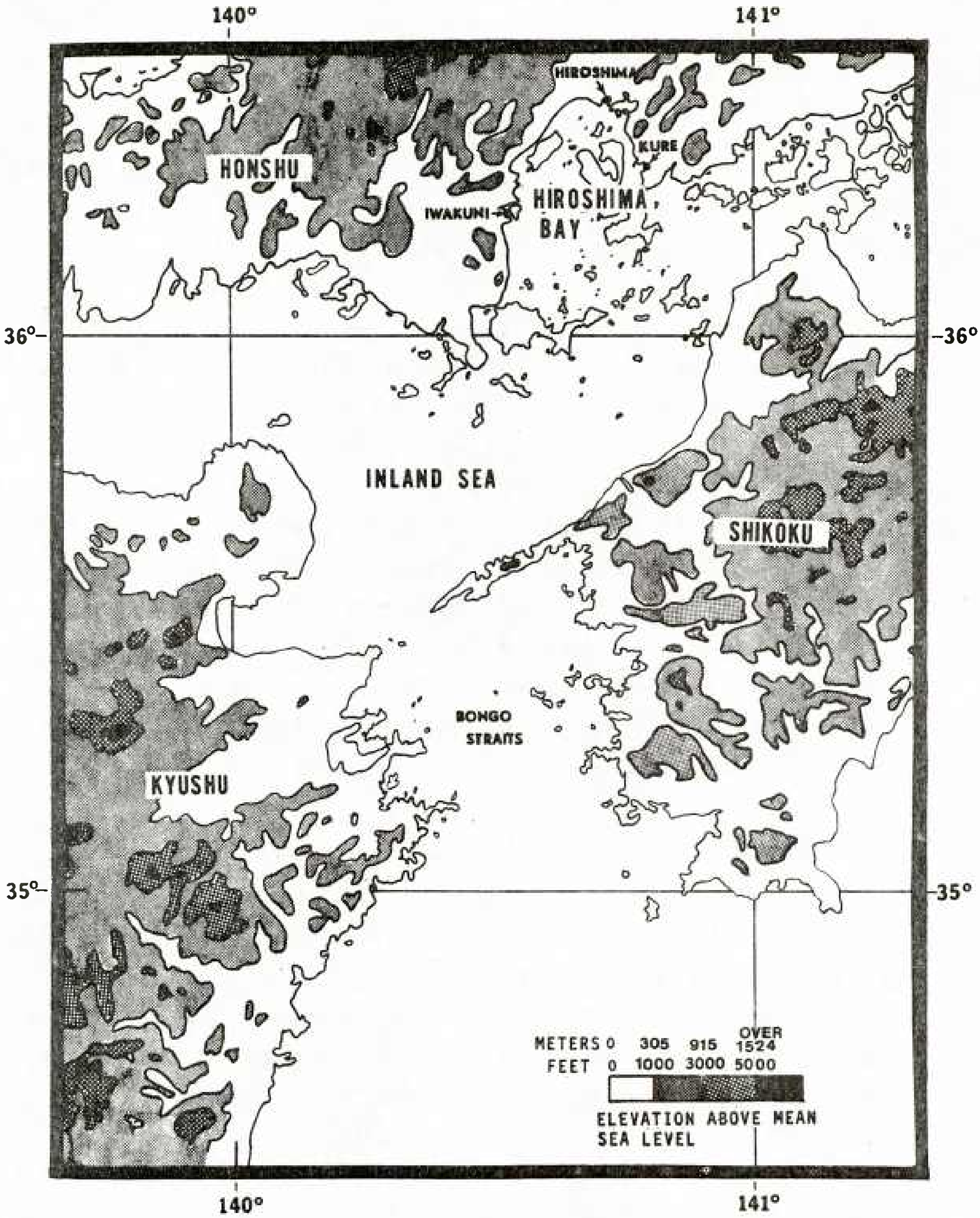

Figure 7. Hiroshima Bay relative to the main Japanese islands of Honshu, Kyushu, and Shikoku.

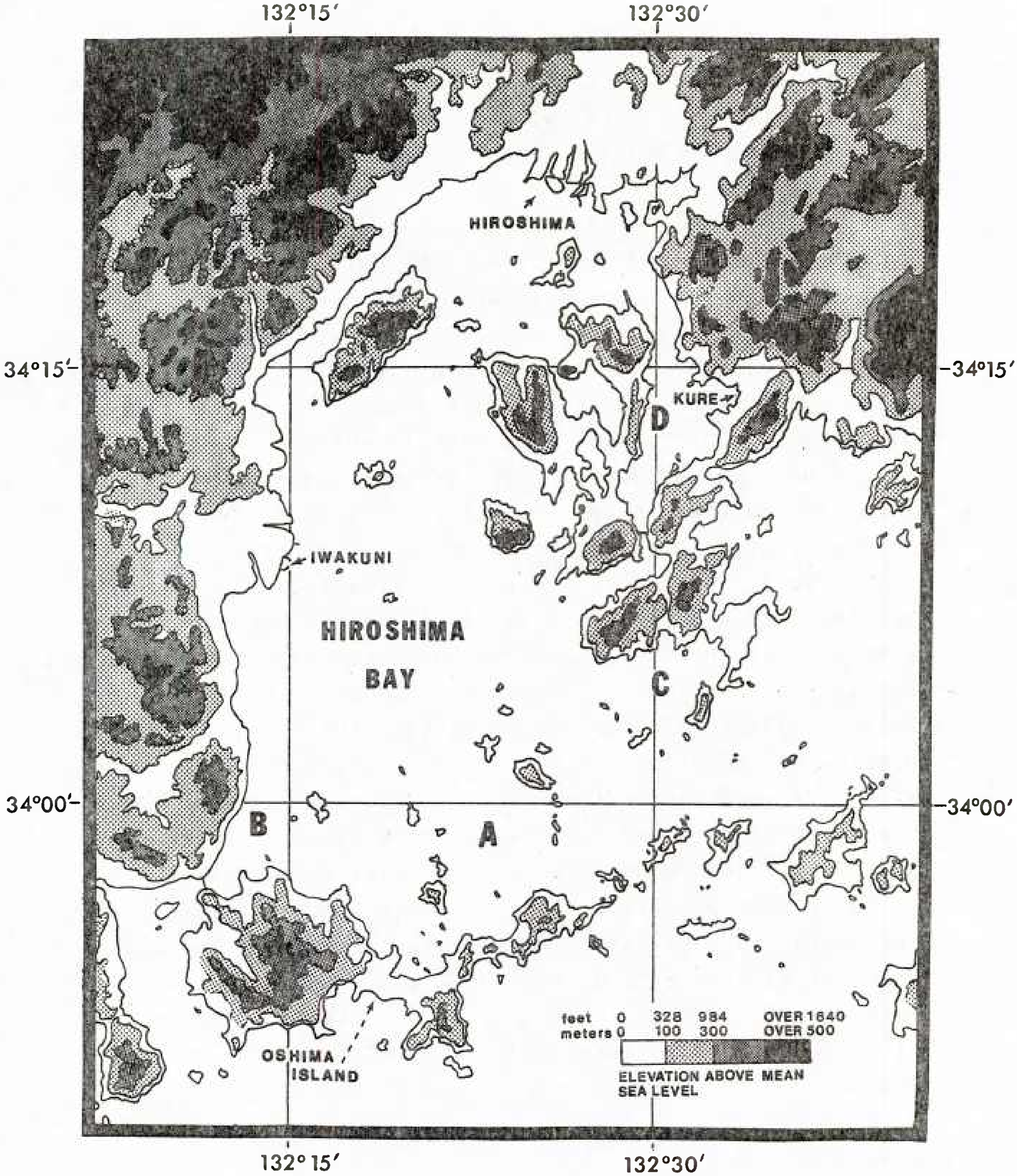

Figure 8. Hiroshima Bay region.

Oshima Island, located in south Hiroshima Bay, and the numerous smaller islands offer effective barriers to winds and seas from the south. They also are responsible for the almost negligible surge and relatively moderate seas in the bay with southerly winds. The lee side of any of the larger islands in the bay area provide substantial protection from both wind and sea. However, draft and the allowable radius of swing must be considered when choosing a refuge. Additionally, many of the islands, both large and small, have commercial oyster beds on their northern sides. Destruction of these beds by foreign flag vessels while seeking refuge should be a major consideration of ship captains so as to eliminate to the greatest degree possible the straining of relations with local fishermen and authorities.

Area A depicted in Figure 8 is free from all the complications listed above and gives excellent protection from the wind and sea, particularly from the south and the west (storm passage to the west). The depth is about 60 ft with a mud bottom characterized by good holding. There should be no problem of crowding by other ships or traffic. Area A would also give good protection from the wind and sea when the winds are from the east and northeast (storm passage to the east). Area C of Figure 8 has all the good qualities of Area A and would provide excellent protection when the winds are from the north and east (storm passage to the east). The one drawback to Area C is a relatively shallow depth of approximately 25 ft at its center. Area B in Figure 8 is a region of strong winds and strong currents and thus should be avoided.

4.2.1 Iwakuni

The port of Iwakuni (commercial) and the military harbor are sometimes mistakenly considered one and the same. The latter, operated by the United States Marine Corps Air Station, is located about three miles south of the commercial port (see Figure 9).

The military port is small in size, has limited facilities, and a minimum depth of 18 feet at its single pier. The harbor is enclosed by a rocky breakwater which is partially covered at high water. The entrance to the harbor is safe for deep draft vessels for a period of only two hours before and after high tides (LST's have clearance at all times). Harbor entrance depth is reduced to two fathoms during low tide.

Four anchorages are available in the outer harbor area with 13 fathoms at low water.

Due to the relative openness of Iwakuni, neither the harbor nor the anchorages are recommended as preferred locations during tropical cyclone passasge. Areas A, C, and D (in Kure Harbor), shown in Figure 8, are the locations recommended.

4.2.2 Kure

Kure Harbor (see Figures 8 and 10), is located in the eastern sector of Hiroshima Bay and is literally landlocked by mountainous terrain, some of which exceed 360 meters (1181 feet) in height. To the north and east the mountains are highest, while to the west the maximum height of the islands ranges from 120 to 240 meters (394-787 feet). Islands to the south and southwest reach heights greater than 360 meters (1181 feet). These mountains are a formidable barrier to strong winds and accompanying seas. However, as can be seen from Figure 8, the ridge lines north of Kure are aligned along a northeast-southwest axis so that one could expect the harbor to experience its strongest winds from the

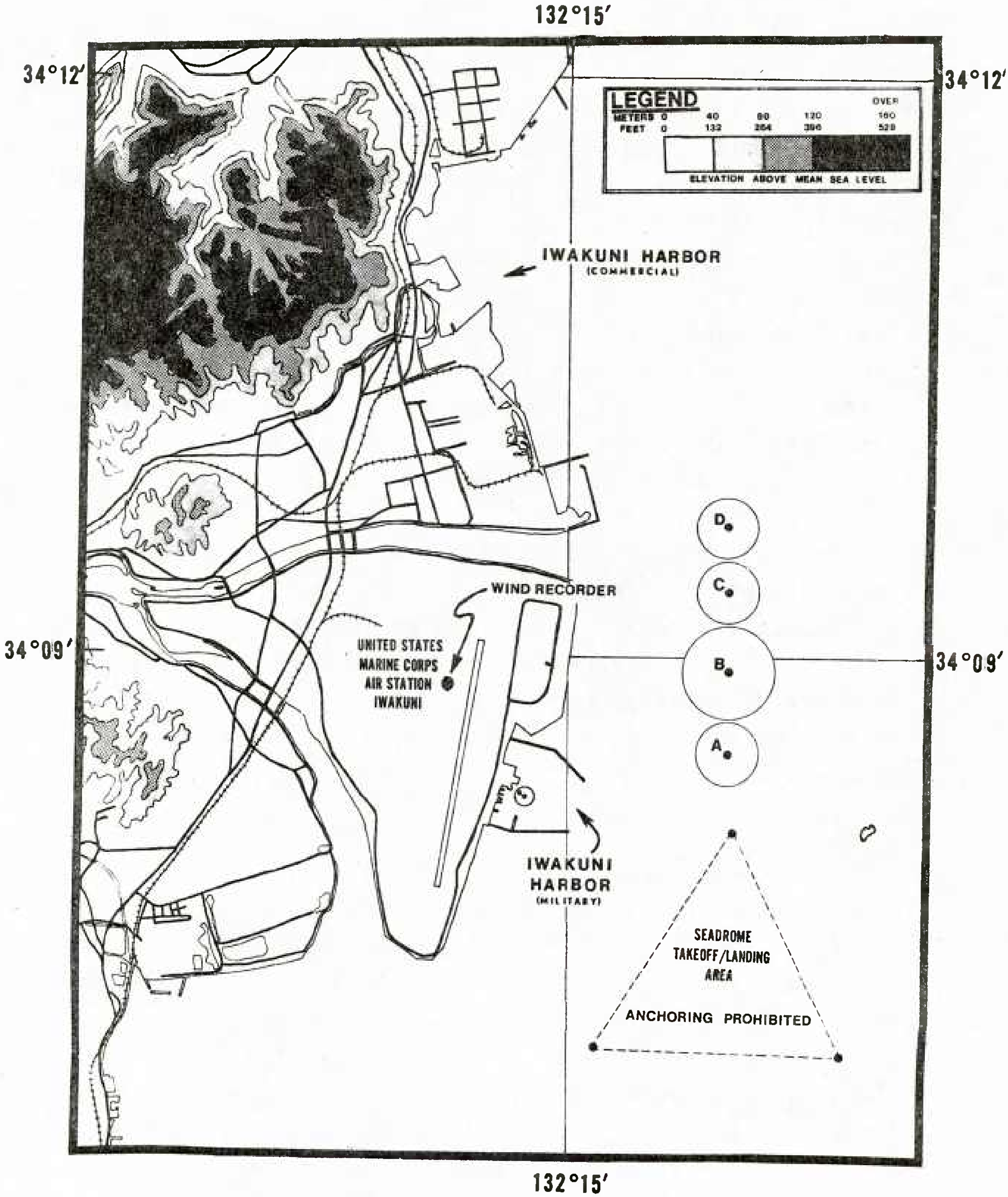

Figure 9. Iwakuni Harbor.

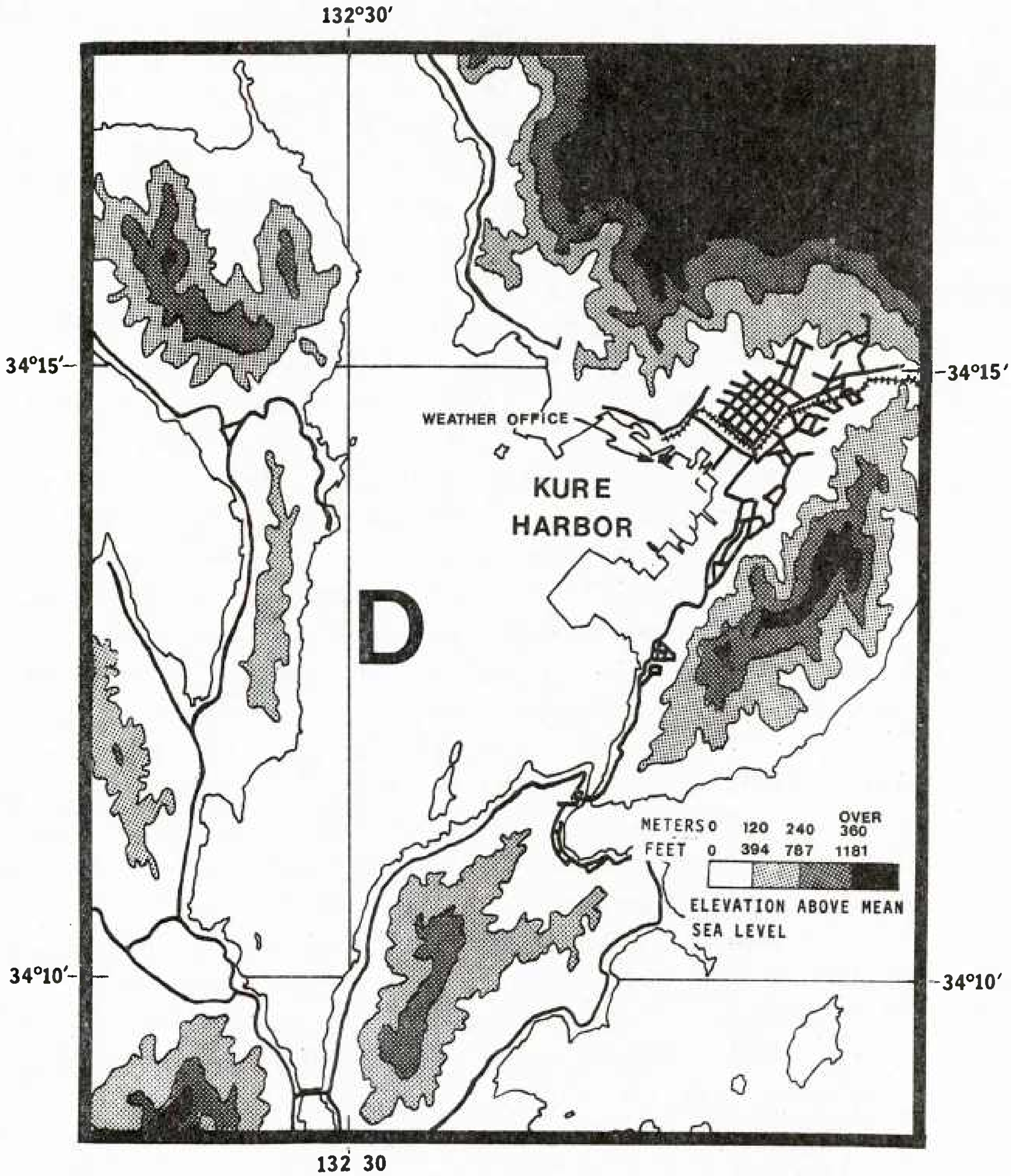

Figure 10. Kure Harbor.

northeast (tropical cyclone passage to the east). Area D in the outer harbor (Figures 8 and 10), is the "typhoon anchorage" suggested for large vessels by Kure Harbor authorities. Area D is extremely well protected from westerly winds and would appear to be most open to northerly winds. The mud bottom, ranging from 18-22 meters (60-72 feet) in depth, is characterized by good holding. Smaller vessels usually utilize the shelter of the various coves found around the periphery of the harbor area or remain at pierside.

The weather office is located in the inner harbor as shown in Figure 10. The winds recorded should be representative of those in the inner harbor but most probably are not representative of the winds in Area D. When the winds are from the north or south, Area D would probably experience higher winds than the inner harbor. When the winds are from the west Area D should experience lighter winds than the inner harbor. However, regardless of wind direction or speed, Area D has been utilized and praised for its security and proclaimed as the best location for large vessels at Kure.

There are six mooring buoys available within the inner harbor as listed in the navigation publications. The Japanese Maritime Self Defense Force (JMSDF) maintains control over a number of other buoys in the inner harbor. Their use must be coordinated through the JMSDF.

Excellent dry docks and repair facilities are available at Kure with a large part of the waterfront area being occupied by the docks and buildings of Ishikawajima-Harima Heavy Industries, LTD (IHI). IHI has the capacity to handle and repair ships over 100,000 tons.

The excellent anchorages, docks and repair facilities coupled with the exceptional protection from winds and seas accompanying tropical cyclones has given Kure the reputation of being one of the best, if not the best, typhoon havens in all of Japan. This reputation and abundance of facilities has in the past lured many ships both large and small to seek refuge in Kure, thus presenting the harbor with its only notable problem -- that of crowding. It should be noted that there have been no incidents related to crowding at Kure since records have been kept; however, the potential is there when a large number of vessels is present.

5. TROPICAL CYCLONES AFFECTING IWAKUNI AND KURE

5.1 CLIMATOLOGY

Tropical cyclones which affect Iwakuni and Kure generally form in an area bounded by the latitudes 5N and 30N between longitudes 120E and 165E. The latitudinal boundaries shift poleward in the summer months and equatorward in winter in response to seasonal changes of the synoptic environment.

It is possible for tropical cyclones to form during any month or season; however, those affecting the Japanese Islands, and hence, Iwakuni and Kure, are confined for the most part to the spring through fall months, with late summer and early fall being the most likely period for an occurance.

For this study the period June-October 1947-1972 was investigated.[2] During this period 74 tropical cyclones passed within 180 n mi of Iwakuni and Kure and are defined as "threats". Figure 11 gives the frequency distribution of threat occurances by 5-day groupings through the five month period. Note in Figure 11 that August and September are the preferred months for storms affecting the Iwakuni/Kure area. Notice also in Figure 11 that a majority of the storms affecting Iwakuni and Kure are of the recurving variety.

Figure 12 illustrates the "threat" tropical cyclones according to the compass octant from which they entered the 180 n mi radius threat area. The circled numbers indicate the total that entered from an individual octant. The adjacent numbers express this as a percentage. It is

[2] From Chin (1972) for years 1947-1970, and from Annual Typhoon Reports for the years 1971-1972 (FWC/JTWC, 1971 and 1972).

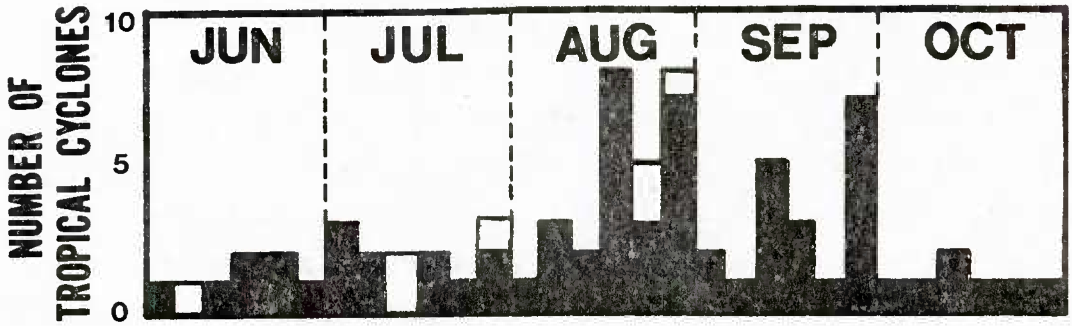

Figure 11. Frequency distribution of the number of tropical cyclones that passed within 180 n mi of Iwakuni and Kure. Subtotals are based on 5-day periods for tropical cyclones that occurred during 1947-1972. Out of a total of 74 storms 67 (91%) were recurvers (had a northeasterly direction of motion at the closest point of approach) and are indicated by the shading.

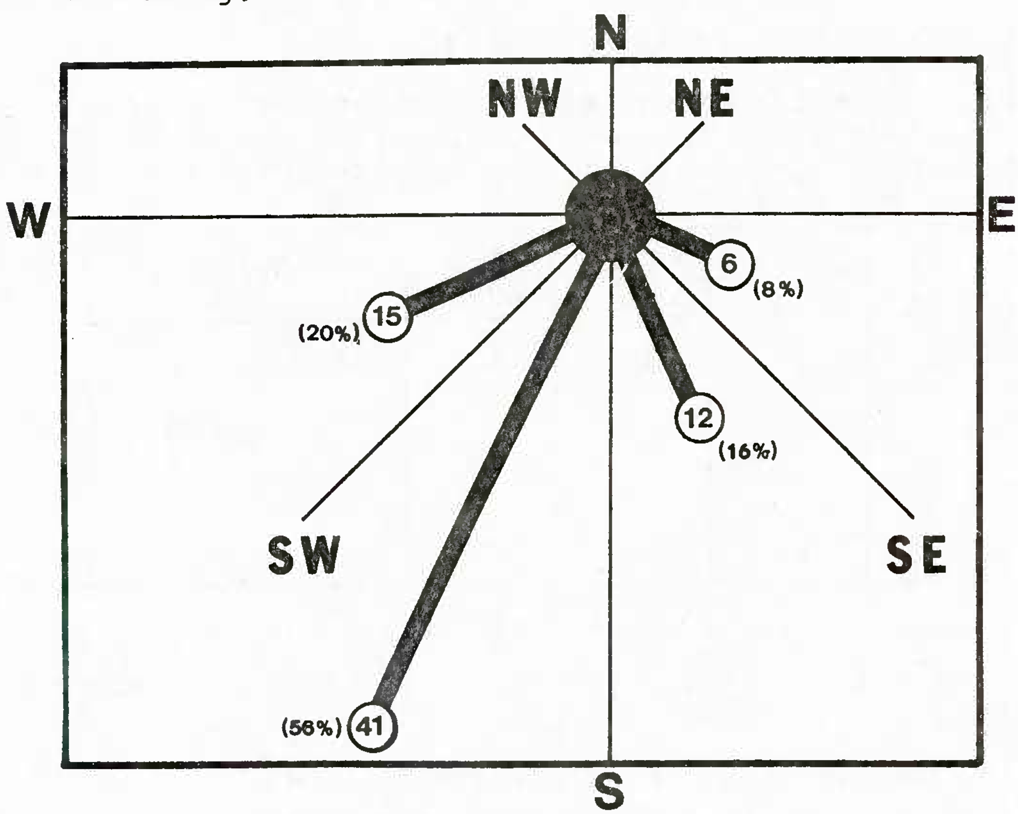

Figure 12. Direction of approach to Iwakuni and Kure of the tropical cyclones (1947-1972) that passed within 180 n mi of Iwakuni and Kure. Circled numbers indicate the number that approached from each octant. The number in parenthesis is the percentage of total sample (74) that approached from that octant.

evident that the majority of tropical cyclones (56%) entered the threat area from a sector extending from the south-southwest.

Figures 13-17 represent an analysis of the probability of a tropical cyclone passing within 180 n mi of Iwakuni and Kure. The solid lines of Figures 13-17 represent the "percent threat" for any storm location. The dashed lines represent approximate approach times to Iwakuni/Kure computed from the average tropical cyclone speed of movement for June-October for tropical cyclones affecting Iwakuni/Kure (Table 1). As an example, in Figure 13 a storm located at 128E and 23N has a 40% probability of passing within 180 n mi of Iwakuni and Kure, and it could hit Iwakuni/Kure in 1-1/2 to 2 days.

Table 1. Listing of the average climatological speeds of tropical cyclones (kt) by 5-degree latitude bands for the months of June-October for the tropical cyclones affecting Iwakuni and Kure.

LATITUDE BAND (N)	AVERAGE FORWARD SPEED OF MOVEMENT (KT)					AVERAGE OF THE 5-MONTHS (KT).
	JUN	JUL	AUG	SEPT	OCT	
30-35 N	25	13	12	20	17	17.4
25-30	17	11	9	15	14	13.2
20-25	12	11	9	11	12	11.0
15-20	10	10	10	11	11	10.4

Note the significant shift in the direction from which the "threat" tropical cyclones approach Iwakuni/Kure in Figures 13-17. In June the "threat" is generally from the southwest; whereas, in July and August, it is from the south and southeast. During September and October the threat is generally out of the south and southwest.

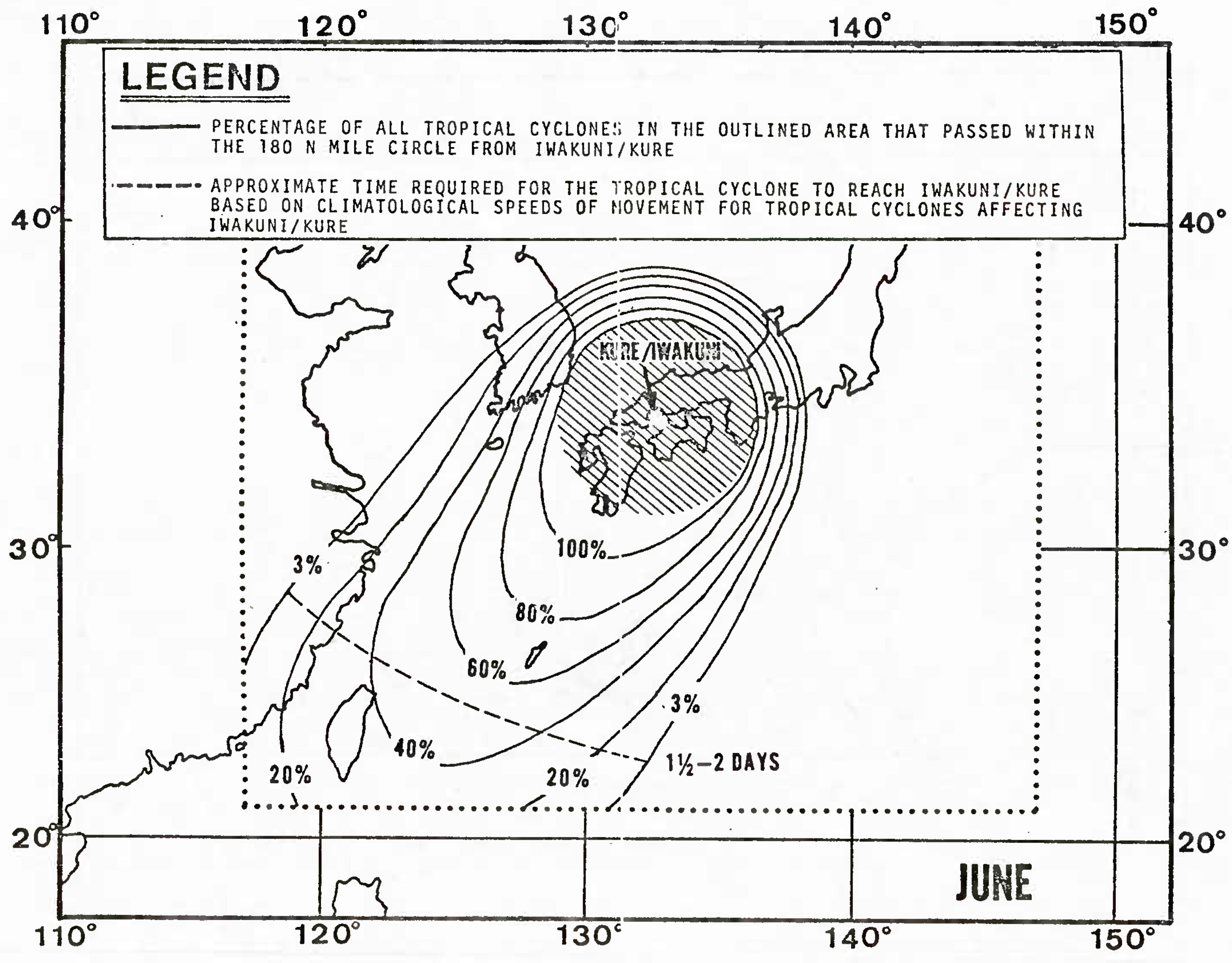

Figure 13. Percentage of tropical cyclones that passed within 180 n mi of Iwakuni/Kure for the month of June (based on data from 1947-1972).

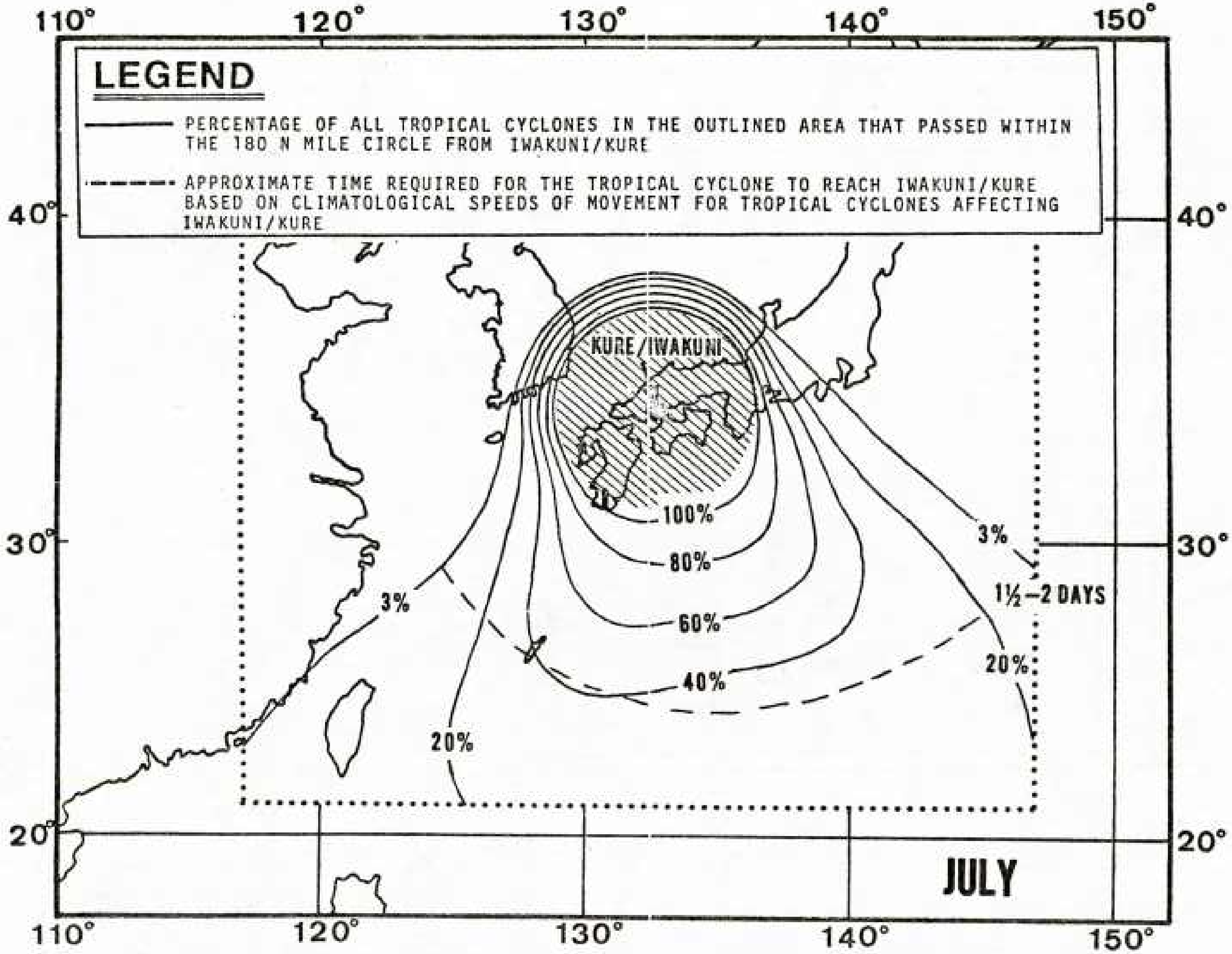

Figure 14. Percentage of tropical cyclones that passed within 180 n mi of Iwakuni/Kure for the month of July (based on data from 1947-1972).

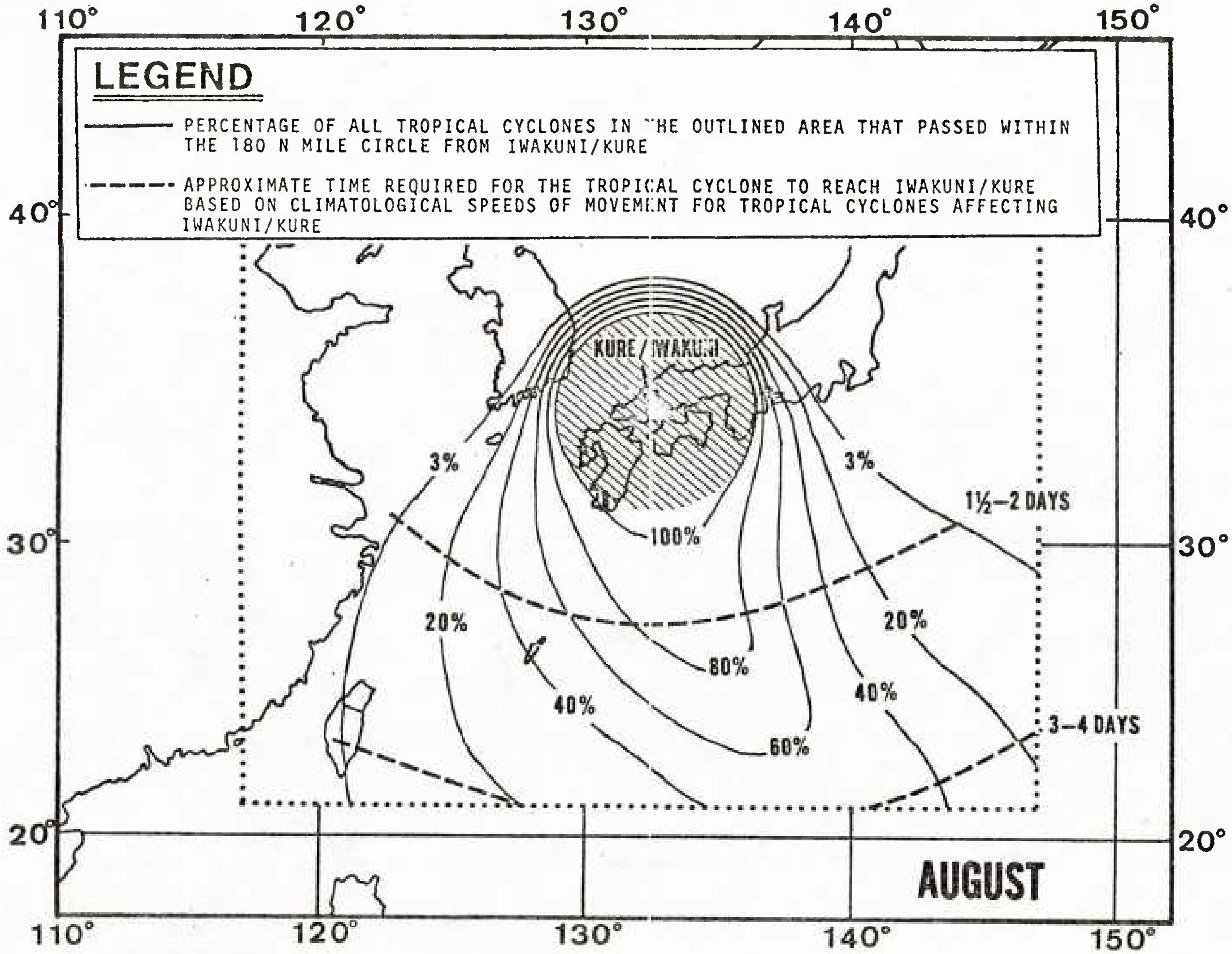

Figure 15. Percentage of tropical cyclones that passed within 180 n mi of Iwakuni/ Kure for the month of August (based on data from 1947-1972).

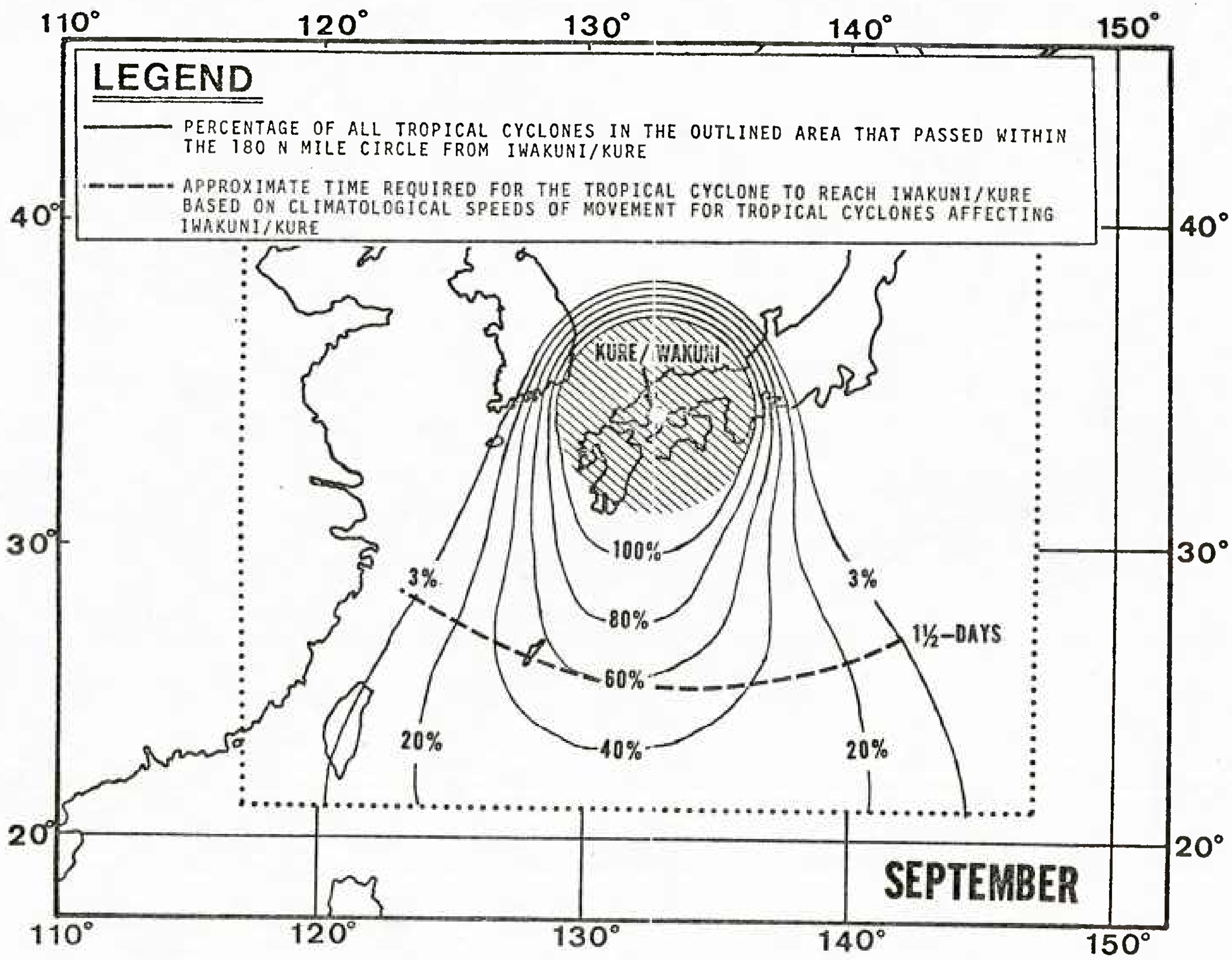

Figure 16. Percentage of tropical cyclones that passed within 180 n mi of Iwakuni/Kure for the month of September (based on data from 1947-1972).

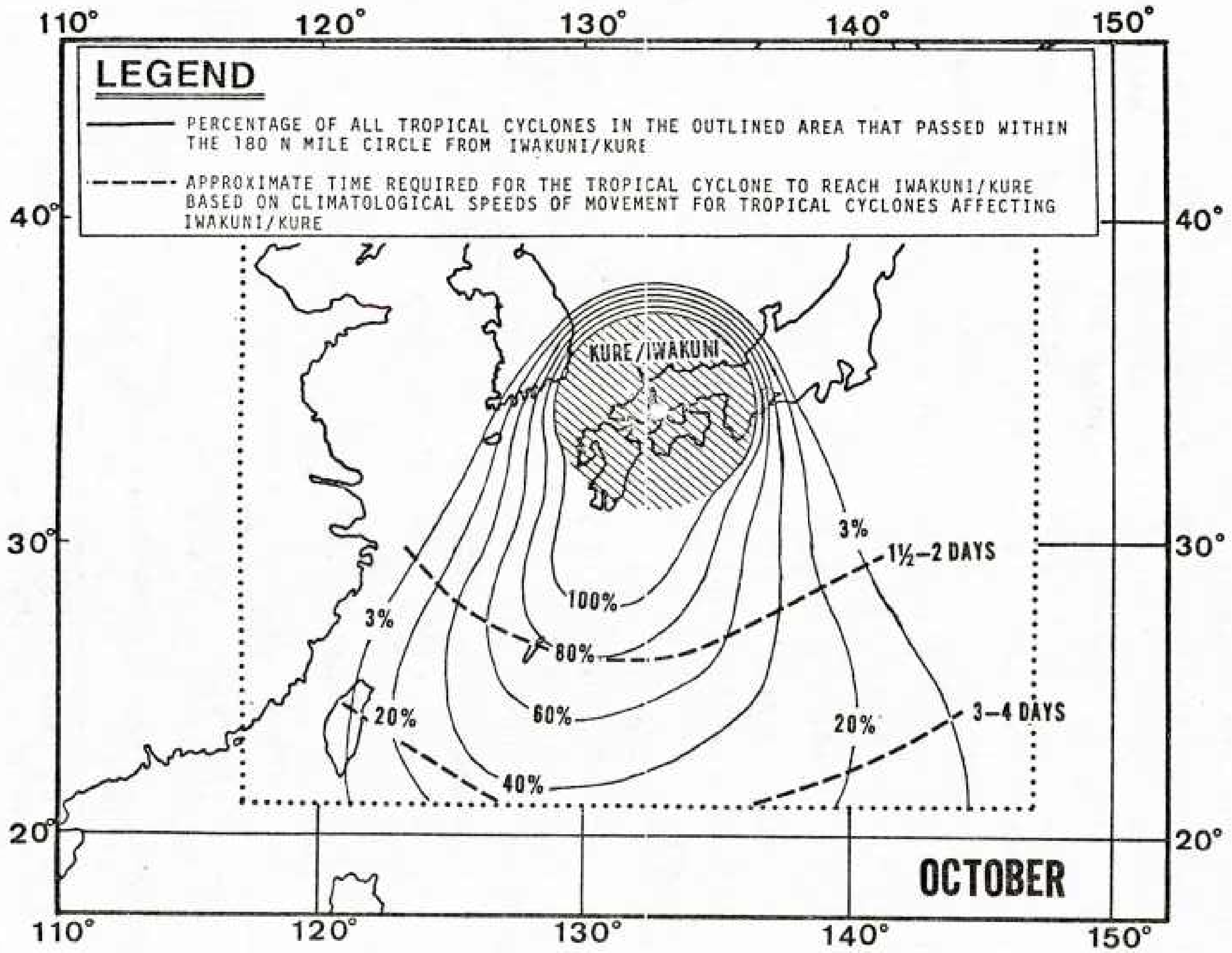

Figure 17. Percentage of tropical cyclones that passed within 180 n mi of Iwakuni/Kure for the month of October (based on data from 1947-1972).

Figures 18-24 depict the tracks of all the tropical cyclones approaching within 180 n mi of Iwakuni and Kure. Notice again that the majority of the storms make their approach from the southwest indicating that they have undergone recurvature and are therefore beginning to weaken even before reaching Japan. This weakening coupled with the mountainous topography surrounding the Hiroshima Bay region accounts for substantially reduced winds associated with tropical cyclones. It must be kept in mind that although the effects of storms are reduced quite effectively, destructive winds can and may occur in the Bay Region with any tropical cyclone.

5.1.1 Tropical Cyclones Affecting Iwakuni

During the June-October period in the 18 years 1955-1973 (excluding 1958), a total of 53 tropical cyclones or an average of 3 tropical cyclones per year have passed within 180 n mi of Iwakuni (and Kure). The largest number that occurred in any single year was 4 (1955, '59, '62, '68, and '71). Table 2 groups the 53 storms according to their effects at Iwakuni. It can be seen in Table 2 that of the total of 53 storms, 14 (26%) resulted in winds of 22 kt or greater and only 6 (11%) gave gale force winds.

Table 2. Extent to which tropical cyclones affected Iwakuni, June through October, 1955-1973 (excluding 1958) (based on hourly wind observations).

Number of tropical cyclones that passed within 180 n mi of Iwakuni.	53
Number of tropical cyclones that resulted in winds greater than or equal to 22 kt.	14 (26%)
Number of tropical cyclones that resulted in winds greater than or equal to 34 kt.	6 (11%)

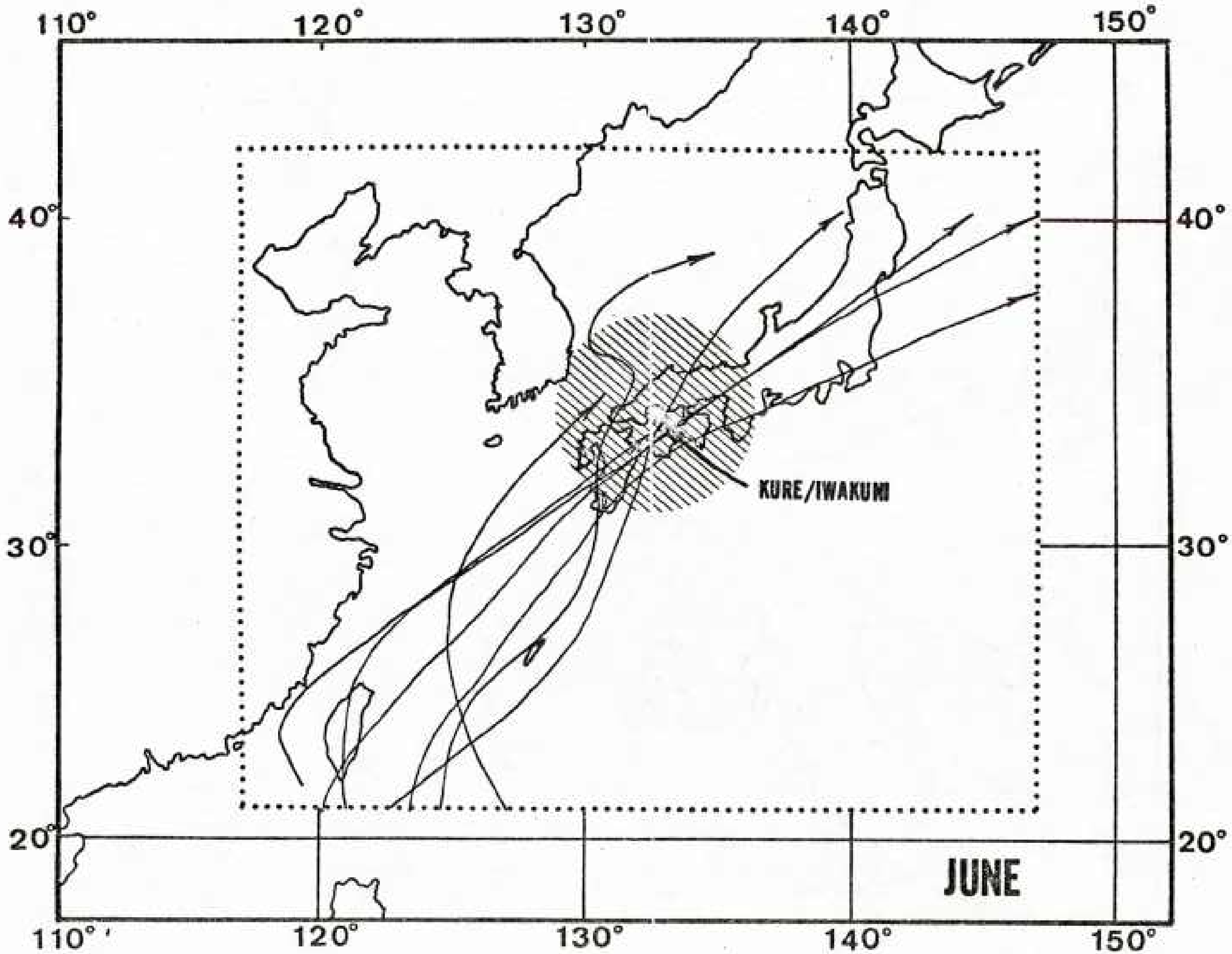

Figure 18. Tracks of tropical cyclones which approached within 180 n mi of Iwakuni/ Kure during the month of June (based on data from 1947-1972).

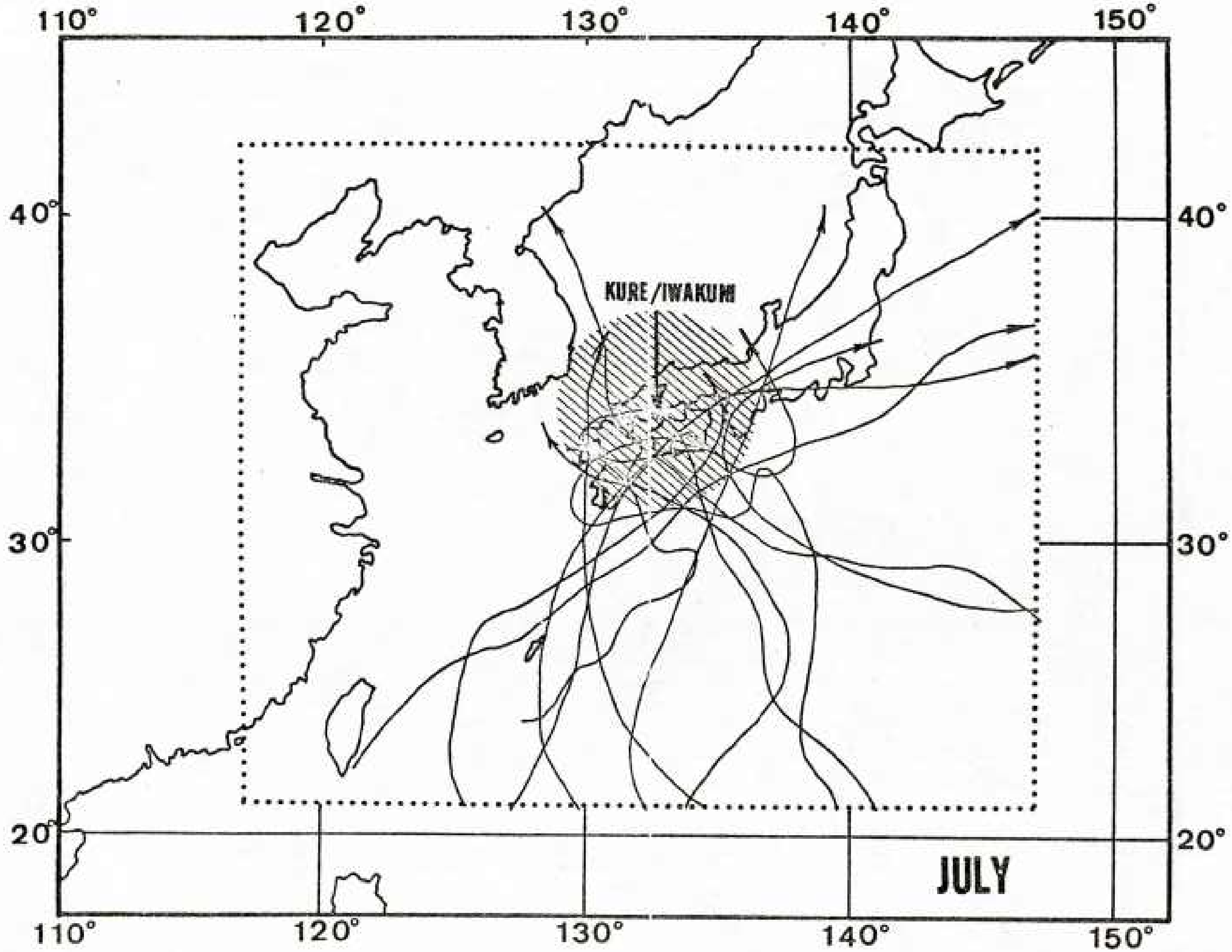

Figure 19. Tracks of tropical cyclones which approached within 180 n mi of Iwakuni/Kure during the months of July (based on data from 1947-1972).

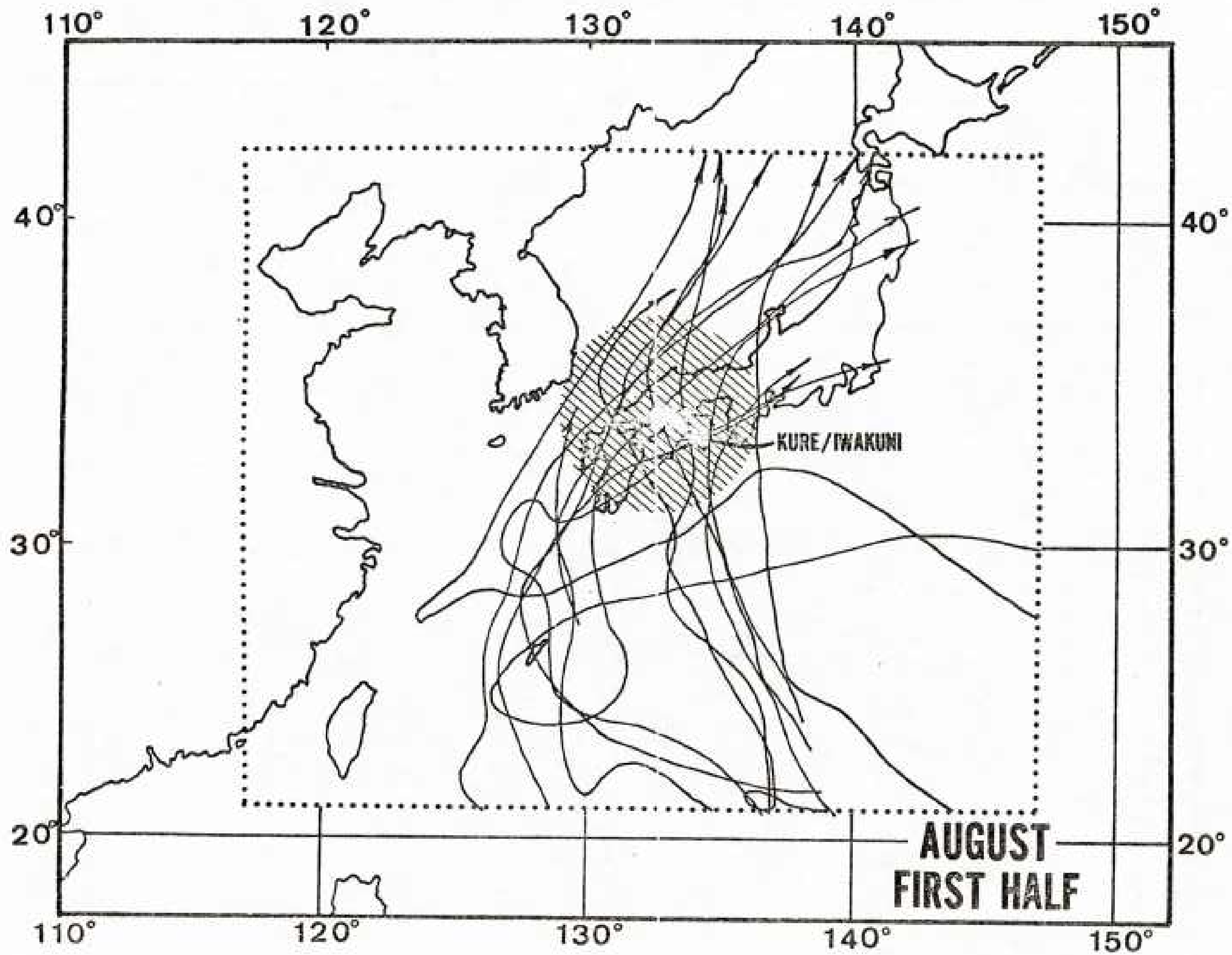

Figure 20. Tracks of tropical cyclones which approached within 180 n mi of Iwakuni/Kure during the first half of August (based on data from 1947-1972).

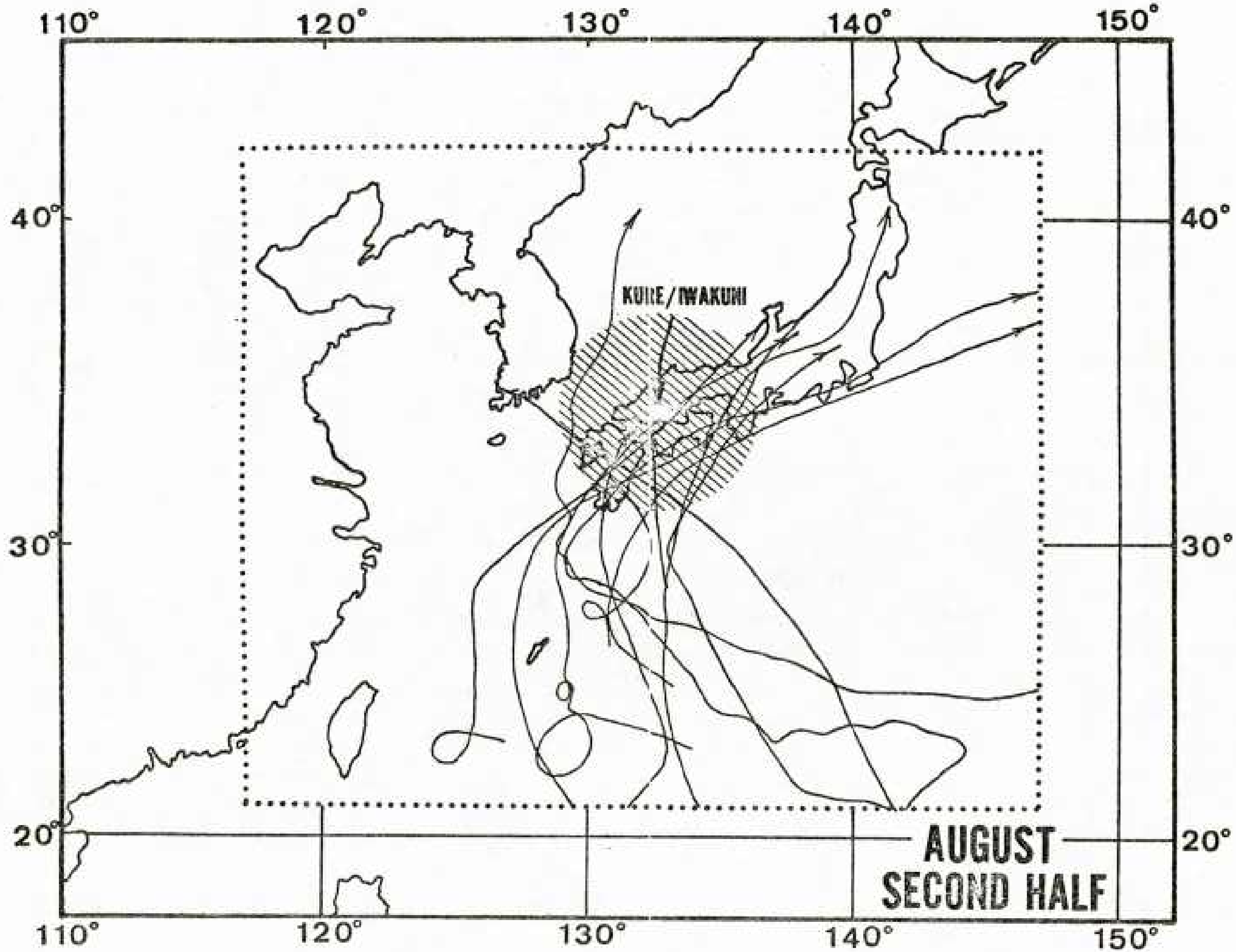

Figure 21. Tracks of tropical cyclones which approached within 180 n mi of Iwakuni/ Kure during the second half of August (based on data from 1947-1972).

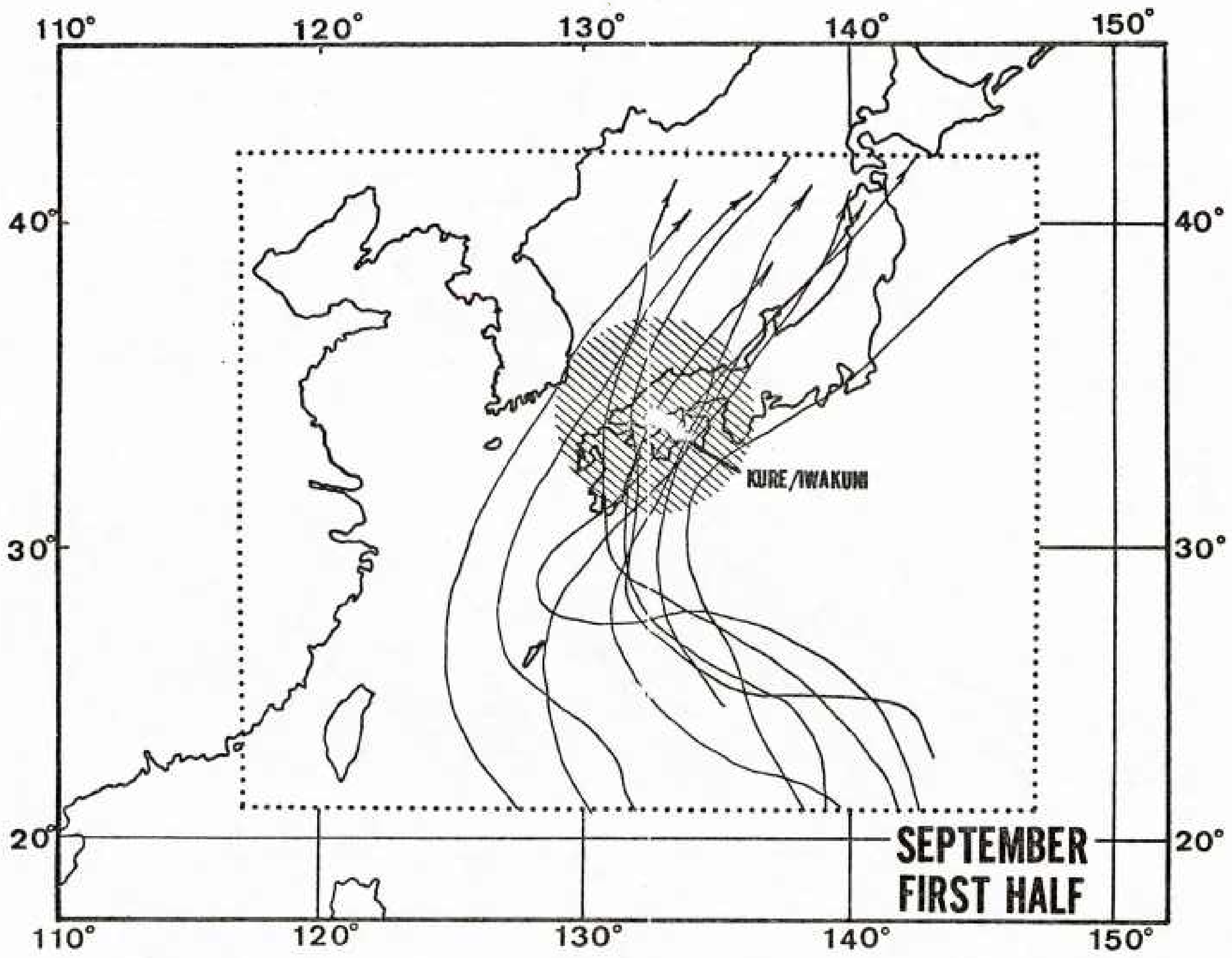

Figure 22. Tracks of tropical cyclones which approached within 180 n mi of Iwakuni/Kure during the first half of September (based on data from 1947-1972).

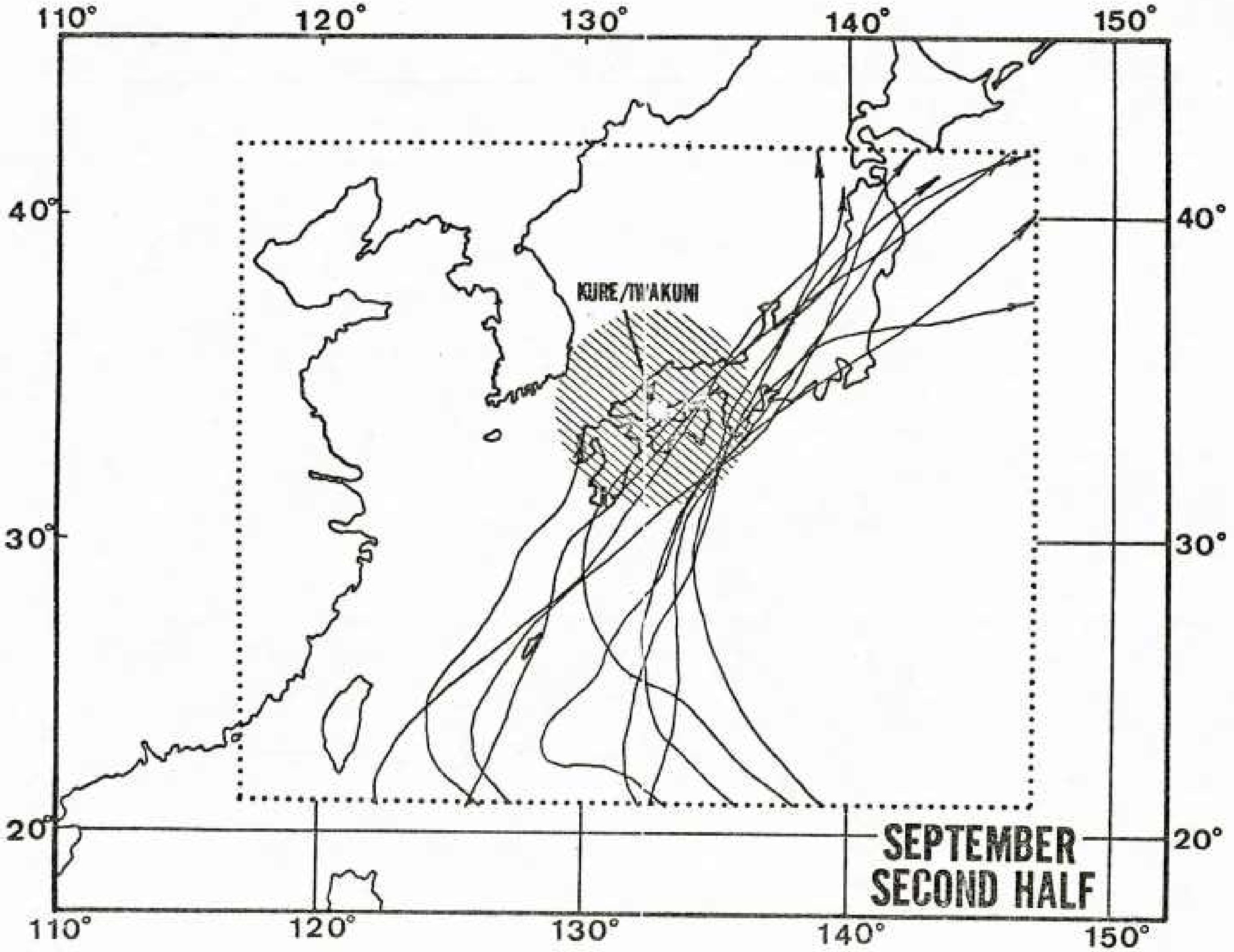

Figure 23. Tracks of tropical cyclones which approached within 180 n mi of Iwakuni/Kure during the second half of September (based on data from 1947-1972).

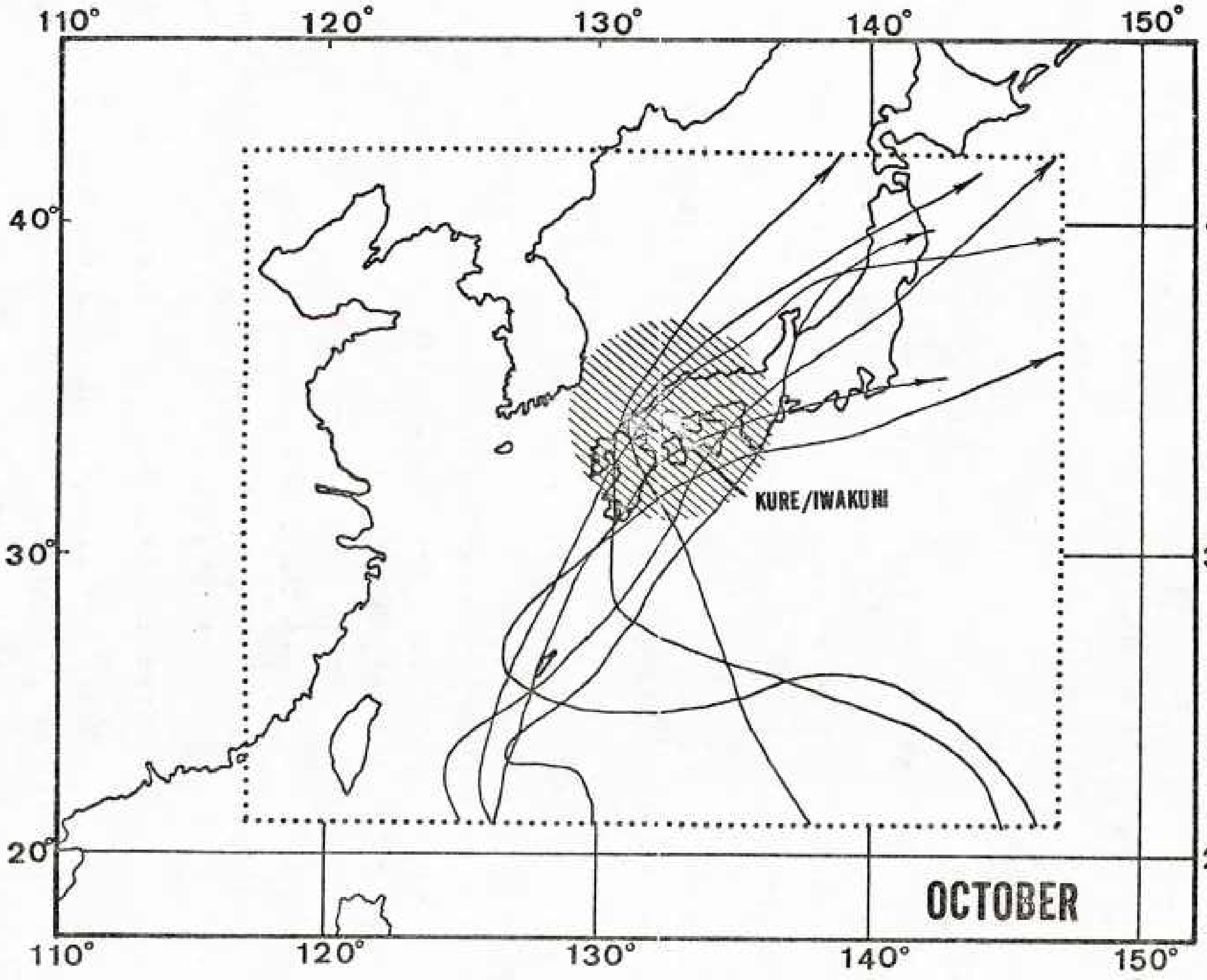

Figure 24. Tracks of tropical cyclones which approached within 180 n mi of Iwakuni/ Kure during the month of October (based on data from 1947-1972).

The strongest sustained winds observed at Iwakuni associated with tropical cyclones were two 45-kt occurrences in 1955. It should be noted that stronger winds have been attributed to extratropical systems in the winter months.

Figure 25 illustrates the positions of the 14 tropical cyclone centers previously mentioned when 22-kt winds first and last occurred at Iwakuni. Figure 26 illustrates the storm locations when winds first and last exceeded 34 kt. Of the 53 tropical cyclones which approached within 180 n mi of Iwakuni (and Kure), 33 (63%) were observed to pass to the east, 19 (36%) to the west, and one directly over the harbor area (1970). These observations, coupled with Figures 25 and 26, indicate a bias for storms passing west of and within 120 n mi of Iwakuni to be those most likely to give strong winds up to and exceeding gale force. The length of the line segments in Figures 25 and 26 also present a rough estimate of wind duration at Iwakuni. For the most part the line segments of Figure 26 represent less than 100 n mi which suggests that a tropical cyclone moving with a speed of 25 kt would give gale force winds at Iwakuni for less than 4 hours.

Due to the counterclockwise rotation of tropical cyclones in the Northern Hemisphere, those storms passing to the west of Iwakuni can be expected to give southerly winds shifting to westerly. If the storm passes to the south and east, southeasterly winds would first be experienced, followed by easterly and/or northerly winds.

5.1.2 Wave Action In Hiroshima Bay (Iwakuni)

Table 3 lists the significant wave heights which could be observed at the Iwakuni Harbor anchorages (Anchorage A-D of Figure 9), and Areas A and C (Figure 8) with various wind speeds and directions. Notice in Table 3 that the maximum wave heights at the Iwakuni Harbor anchorages (A through D) will occur when the winds are from the south (storm passage

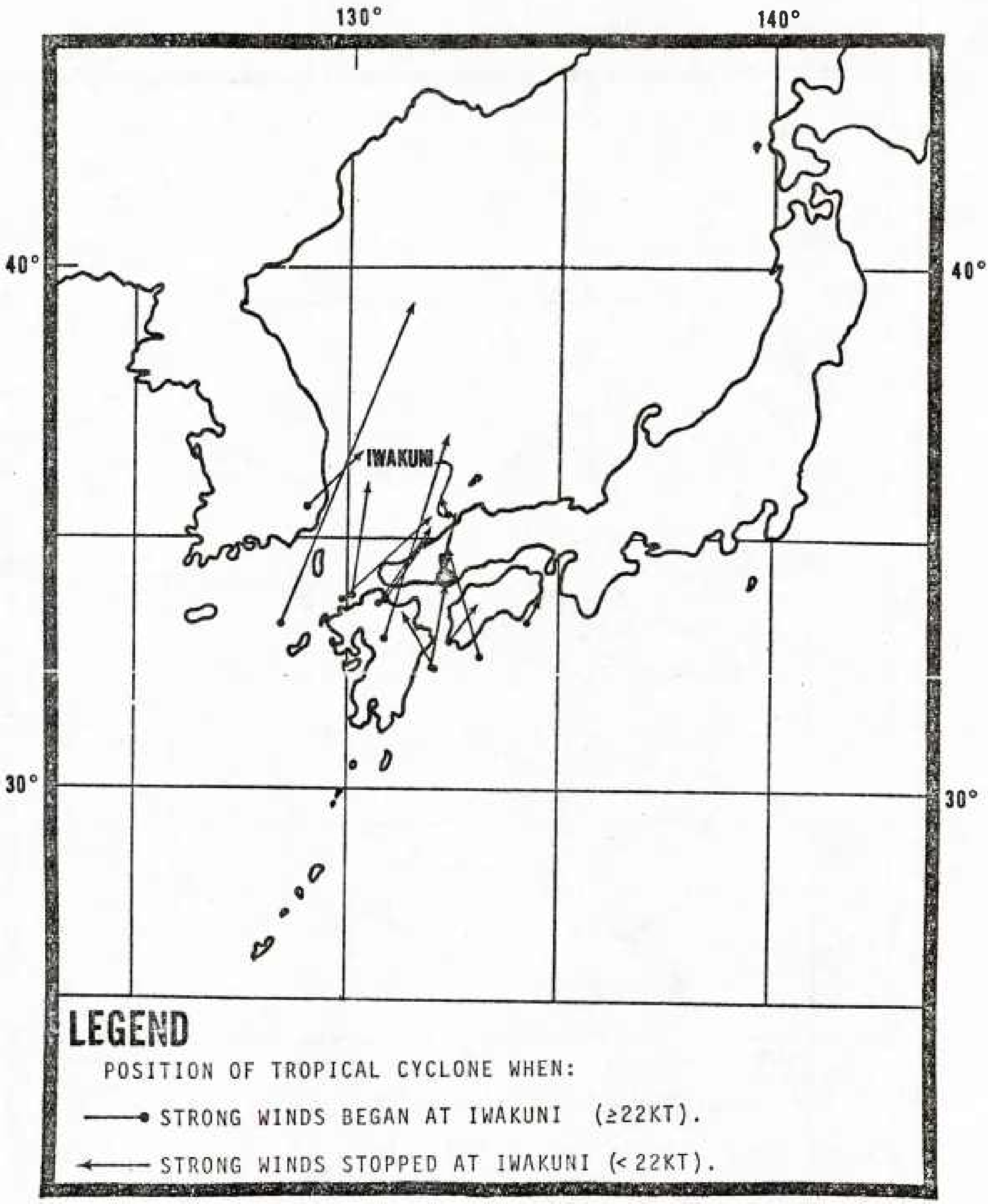

Figure 25. Position of tropical cyclone centers when winds greater than or equal to 22 kt first and last occurred at Iwakuni (based on data from 1955-1973, excluding 1958).

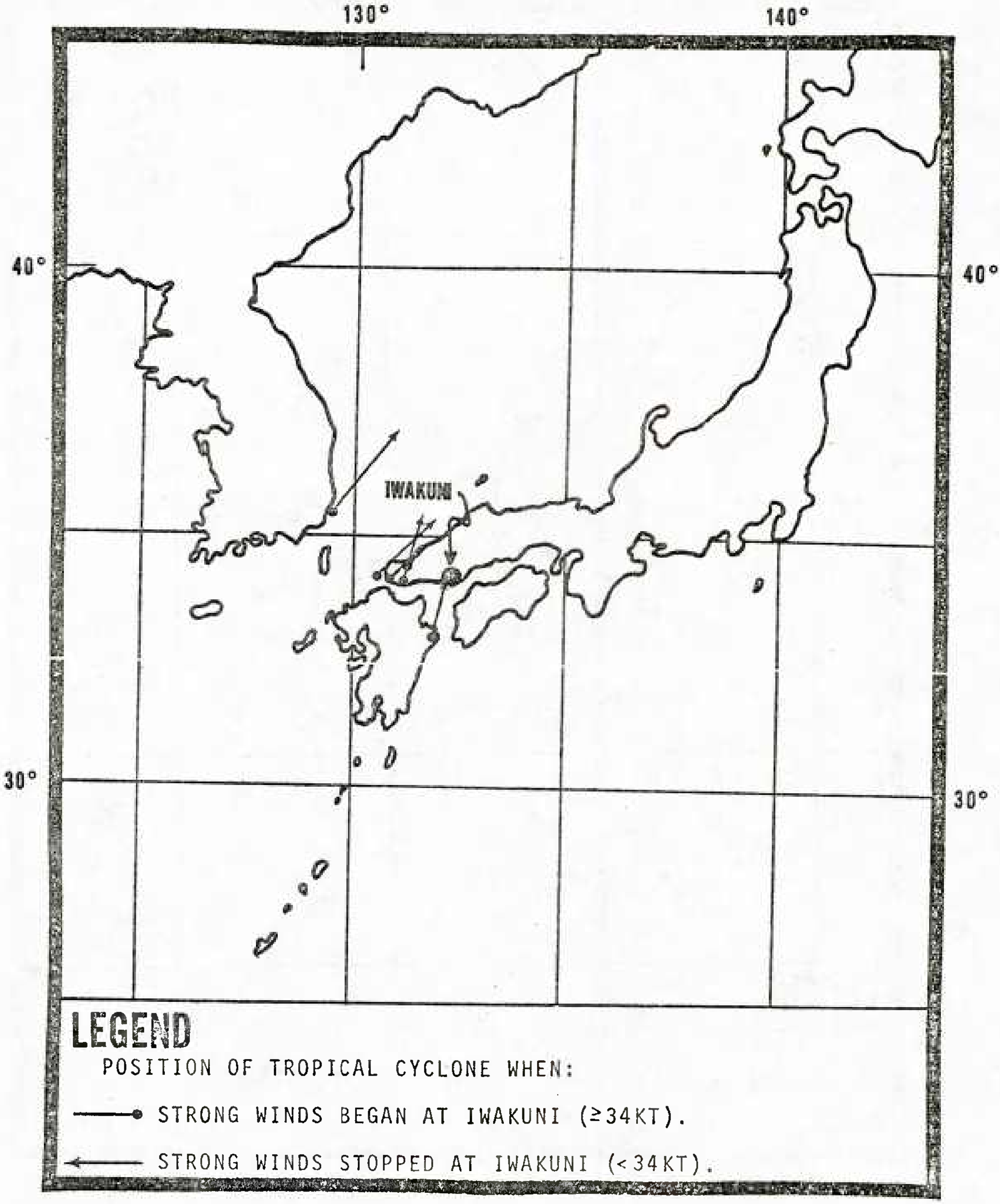

Figure 26. Position of tropical cyclone centers when winds greater than or equal to 34 kt first and last occurred at Iwakuni (based on data from 1955-1973, excluding 1958).

to the west), while Areas A and C will have waves 7 ft or less. Also notice in Table 3 that winds from the north give the highest waves in Area A and winds from the west give the highest waves in Area C.

Table 3. Significant wave heights ($\bar{H}$ 1/3) in ft that could be expected at the Iwakuni anchorages (A-D of Figure 9), and Areas A and C (Figure 8) with various wind speed and direction. X indicates negligible wave heights (less than 4 ft).

WIND (kt)	IWAKUNI ANCHORAGES				AREA A				AREA C			
	N	S	E	W	N	S	E	W	N	S	E	W
35 kt	4 ft	5	4	X	6.0	X	X	X	X	X	X	4.5
45	5	6.5	5.5	X	7.0	5.0	5.5	5.5	X	5.0	X	6.5
55	6.5	9.0	6.0	X	9.5	6.0	6.5	6.5	X	6.0	4	8.5
65	8.5	11	7.0	X	10.5	6.5	7.0	7.0	5	7.0	5	10.0

5.1.3 Storm Surge In Hiroshima Bay (Iwakuni)

Storm surge may be defined as an abnormal rise of the sea along a shore as the result of winds and pressure drop associated with a storm. These surges are most pronounced along the south coast of the Japanese island chain where the bays are open to the Pacific Ocean.

Due to its sheltered position within the Inland Sea, the numerous islands (notably Oshima Island to the south), and the fact that winds are significantly reduced before reaching the Hiroshima Bay area, storm surge is negligible. These points were emphasized quite strongly in conversations with local harbor and weather authorities. Records are not kept on storm surge in Hiroshima Bay and no significant damage or incident has been attributed to this phenomenon.

5.1.4 Tropical Cyclones Affecting Kure

During the June-October periods in the 18 years 1955-1972, a total of 53 tropical cyclones or an average of 3 tropical cyclones per year passed within 180 n mi of Kure. The largest number that occurred in any single year was 4 (1955, '59, '62, '68, and '71). Table 4 groups the 53 storms according to their effects on Kure. It can be seen in Table 4 that of the total of 53 storms, 24 (45%) resulted in winds greater than or equal to 22 kt and only 6 (11%) gave winds greater than or equal to 34 kt.

Table 4. Extent to which tropical cyclones affected Kure, June through October, 1955-1972.

Number of tropical storms that passed within 180 n mi of Kure	53
Number of tropical cyclones that resulted in winds greater than or equal to 22 kt	24 (45%)
Number of tropical cyclones that resulted in winds greater than or equal to 34 kt	6 (11%)

Figure 27 shows the positions of the tropical cyclone centers when winds first and last exceeded 22 kt at Kure. Figure 28 illustrates the storm centers when the winds first and last exceeded 34 kt. As noted earlier, out of the total of 53 tropical cyclones approaching within 180 n mi of Kure (and Iwakuni) during the period investigated, most passed to the east (approximately 63%) with one occurrence of a storm passing directly over the harbor area -- Typhoon Anita in 1970.

It can be seen in Figures 27 and 28 that the storm centers must be north of 31N before winds exceeding 22 kt and north of 32N before gale force winds are observed at Kure.

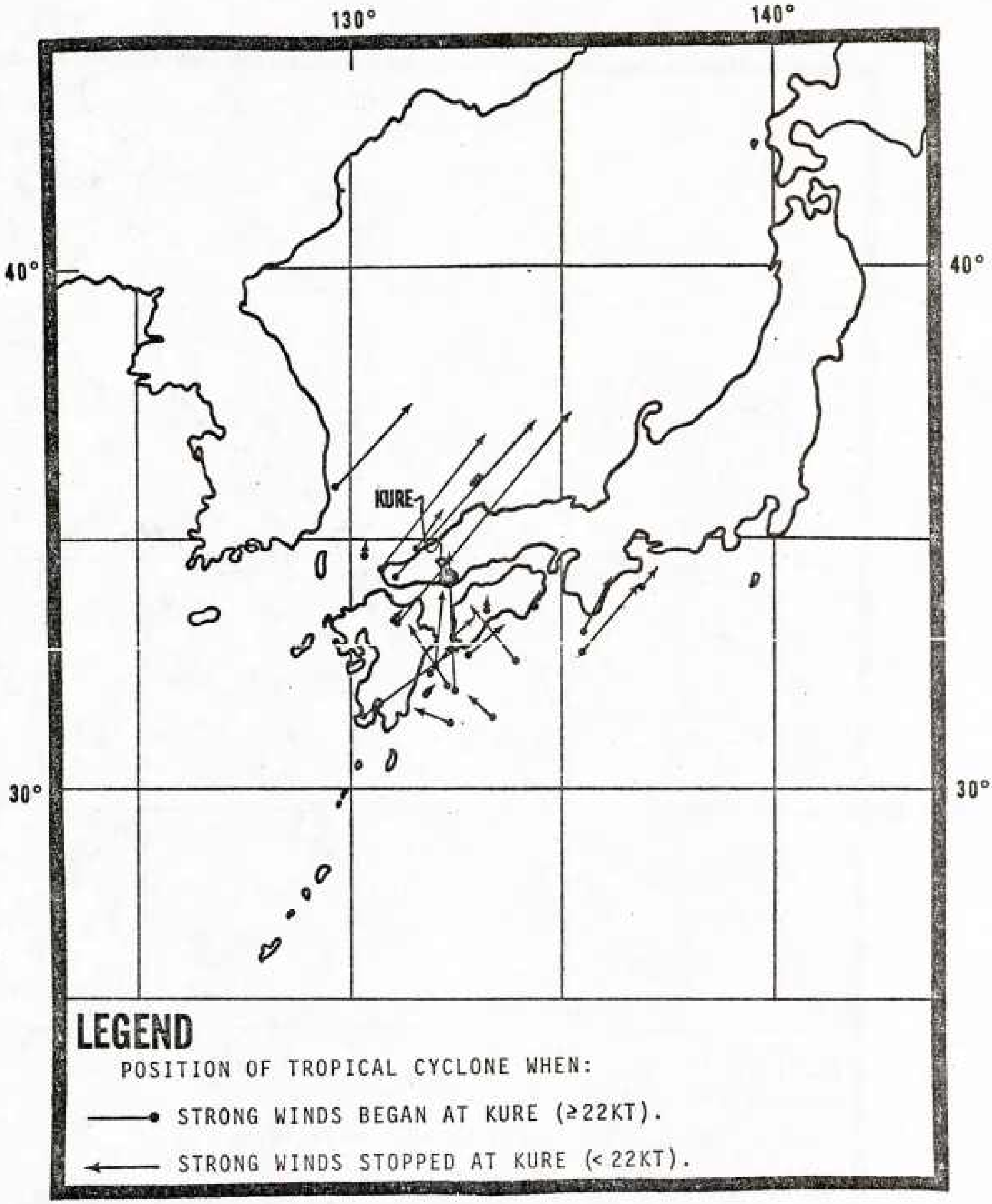

Figure 27. Position of tropical cyclone centers when winds greater than or equal to 22 kt first and last occurred at Kure (based on data from 1955-1972).

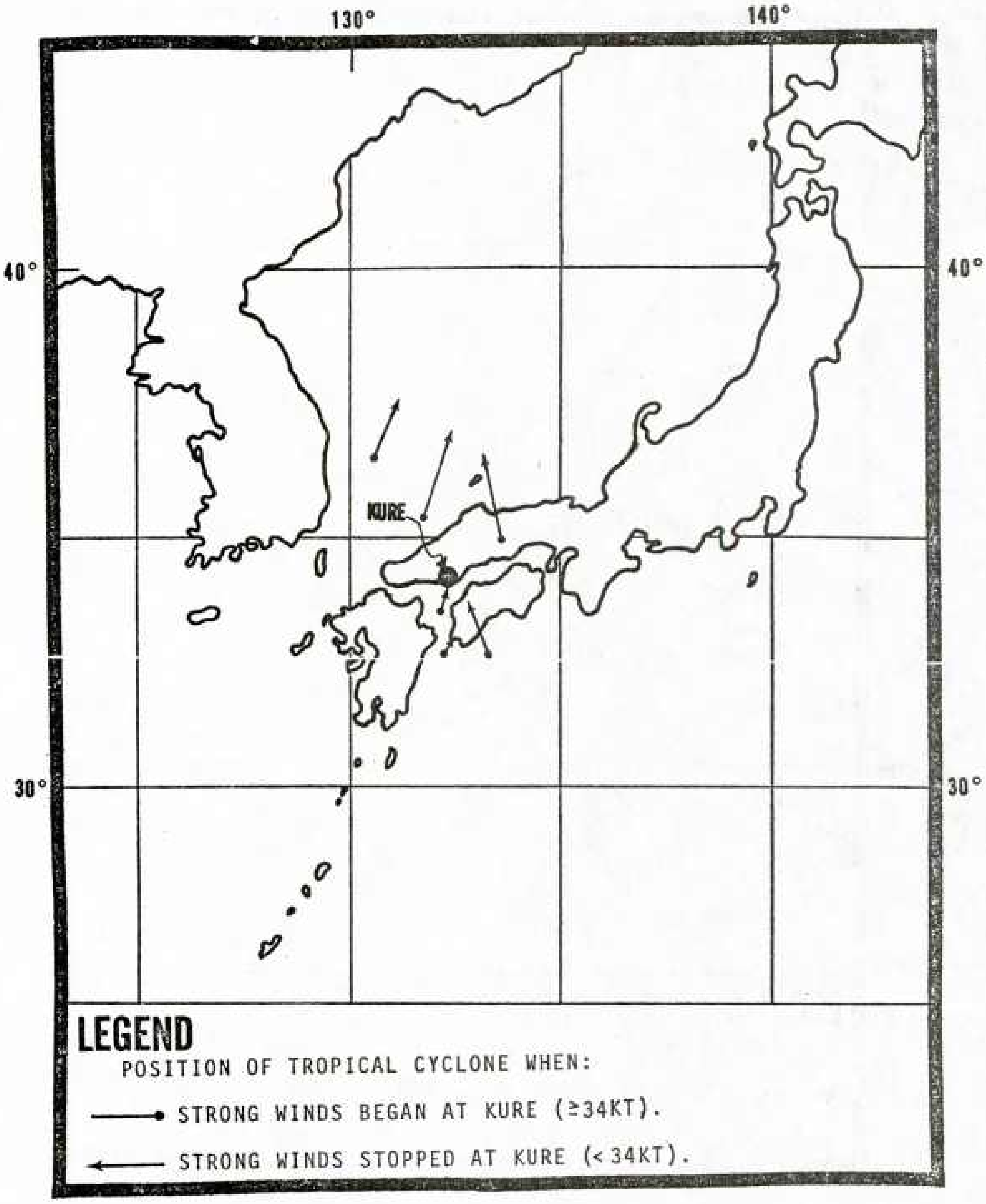

Figure 28. Position of tropical cyclone centers when winds greater than or equal to 34 kt first and last occurred at Kure (based on data from 1955-1972).

Figure 27 also suggests that storms passing to the west may have a longer duration of winds in the 22-33 kt range, than storms which pass to the east.

The strongest winds recorded at Kure that could be associated with a tropical cyclone in the period 1937-1972 were in 1970, when Typhoon Anita passed directly over the city. The maximum sustained winds recorded were 51 kt from the northeast. It should be noted that stronger winds have been attributed to extratropical systems in the winter months.

5.1.5 Wave Action In Kure Harbor

Table 5 lists the significant wave heights which could be observed in Area D at Kure (see Figures 8 and 10) with winds of various speeds and directions. Observe in Table 5 that the maximum significant wave heights will occur when winds are from the north. Wave action in the inner harbor should be less than that in Area D.

Table 5. Significant wave heights ($\bar{H}$ 1/3 in ft) that could be expected in Area D of Kure Harbor area with wind speeds of 35, 45, 55, and 65 kt. X indicates negligible wave heights (less than 4 ft).

WIND SPEED (kt)	WIND DIRECTION			
	N	S	E	W
35	4.0 ft	X	X	X
45	5.5	X	X	X
55	6.5	4.0	4.5	X
65	7.5	5.0	5.0	X

5.1.6 Storm Surge In Kure Harbor

Storm surge is defined as an abnormal rise of the sea along a shore resulting from winds and the pressure drop associated with intense storms. Storm surge is adjudged to be negligible and hence should produce no significant damage.

6. PREPARATION FOR HEAVY WEATHER IN THE IWAKUNI/KURE REGION

6.1 TROPICAL CYCLONE WARNINGS

Through aircraft reconnaissance and satellite observations, modern techniques for locating tropical cyclones and monitoring their progress have become quite sophisticated. Nevertheless, the present state of meteorological knowledge does not permit a perfect prediction of storm movements. As stated previously, many variables exist which can alter the path of a typhoon; hence every typhoon should be treated with the utmost respect.

Tropical cyclone warnings including 24-, 48-, and 72-hr forecasts are issued by the Fleet Weather Central/Joint Typhoon Warning Center (FWC/JTWC), Guam. When the initial warning of a tropical depression, storm or typhoon is received, a running plot of the following should be maintained:

1. Ships position,
2. Actual and forecast tropical cyclone center positions,
3. Area of dangerous winds (30 kt and above).

Appendix 1 to Annex H of CINCPACFLT OPORD 201-(YR) describes how to calculate the "Danger Area" of a tropical cyclone. A copy of this pertinent section is included in Appendix B of this report.

In Appendix B, an average 24-hr forecast position error of 135 n mi is commonly used. Burroughs and Brand (1972) found in their study that the average 24-hr forecast error for recurving typhoons is 141 n mi. Additionally Burroughs and Brand found that for forecast positions verifying after the point of recurvature, the error was 165 n mi. Since the majority of "threat" tropical cyclones affecting Iwakuni and Kure are of the recurving type, it may be prudent to use a radius greater than 135 n mi when determining the danger area.

There is no local heavy weather readiness procedure established for ships in port at Iwakuni and Kure. However, there are certain precautions suggested by Japanese Maritime Safety Agency officials. These suggestions plus additional conclusions for particular areas (Areas A, C, and D in Figures 8 and 10) form the basis for the following sections.

6.2 EVASION RATIONALE

A most important aspect of any decision concerning heavy weather is an early appraisal of the threat posed by an individual tropical cyclone. The preparations must begin when enough time remains to allow flexibility in the evasion plan. To facilitate early action, the following time table has been set up in conjunction with Figures 29 through 33.

I. An existing tropical cyclone moves into, or development takes place in area A of Figures 29-33 with forecast movement toward Iwakuni/Kure.

   a. Review material condition of ship. It may be necessary to move to recommended anchorages.

   b. Reconsider any maintenance that would render the ship incapable of getting underway in 48 hr if need be, or riding out the storm at anchor.

   c. Plot FWC/JTWC, Guam warnings if issued and construct the danger area. Reconstruct the danger area for each new warning.

II. Tropical cyclone enters area B of Figures 29-33, with forecast movement toward Iwakuni/Kure.

   a. Reconsider any maintenance that would render the ship incapable of getting underway or moving to a new anchorage prior to expected time of strong winds within the area.

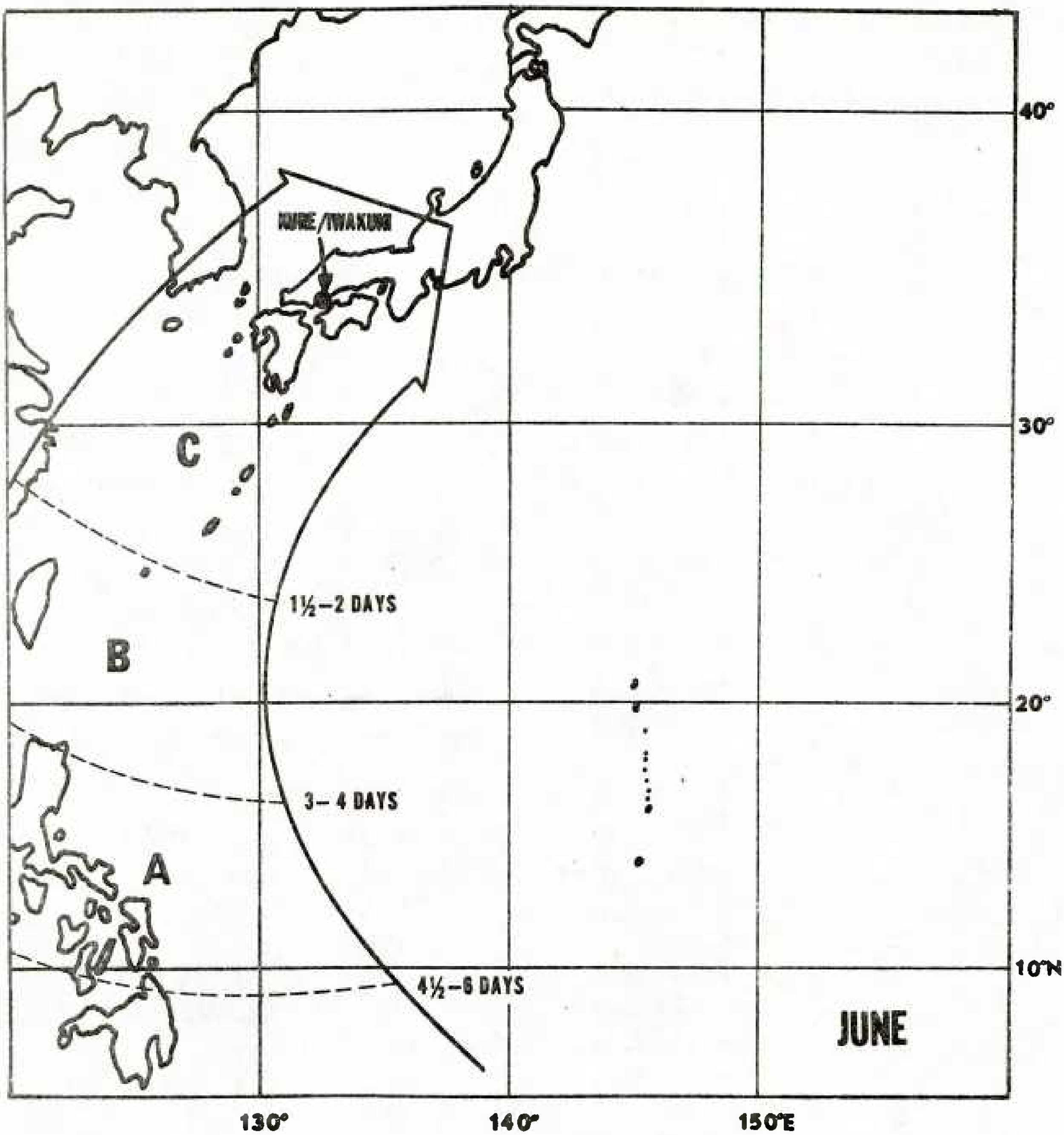

Figure 29. Tropical cyclone threat axis for the month of June. The area within the arrow approximates a 30% or greater probability of a tropical cyclone coming within 180 n mi of Iwakuni/Kure. Approach times are based on typical speeds of movement for tropical cyclones affecting Iwakuni/Kure.

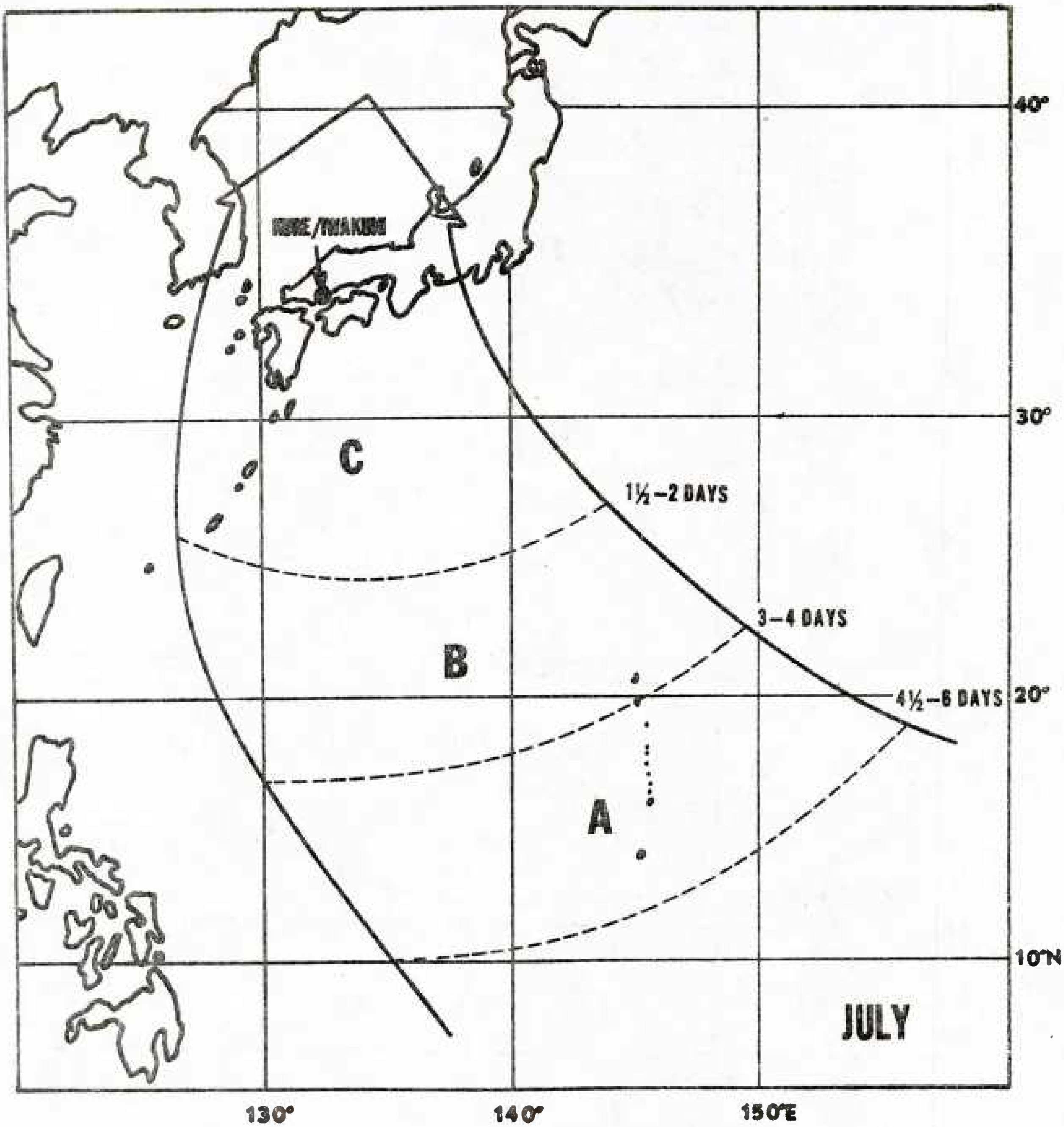

Figure 30. Tropical cyclone threat axis for the month of July. The area within the arrow approximates a 30% or greater probability of a tropical cyclone coming within 180 n mi of Iwakuni/Kure. Approach times are based on typical speeds of movement for tropical cyclones affecting Iwakuni/Kure.

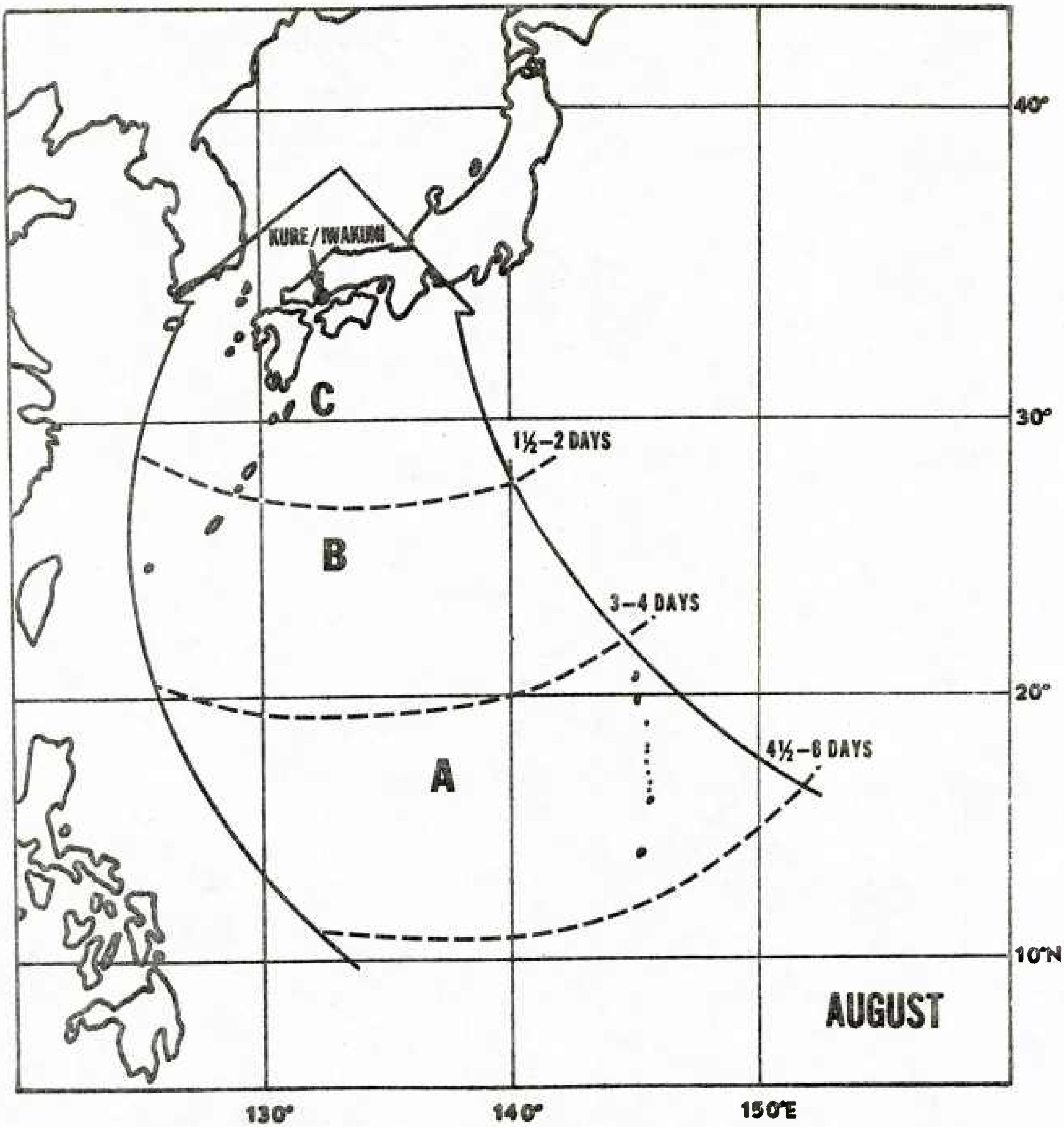

Figure 31. Tropical cyclone threat axis for the month of August. The area within the arrow approximates a 30% or greater probability of a tropical cyclone coming within 180 n mi of Iwakuni/Kure. Approach times are based on typical speeds of movement for tropical cyclones affecting Iwakuni/Kure.

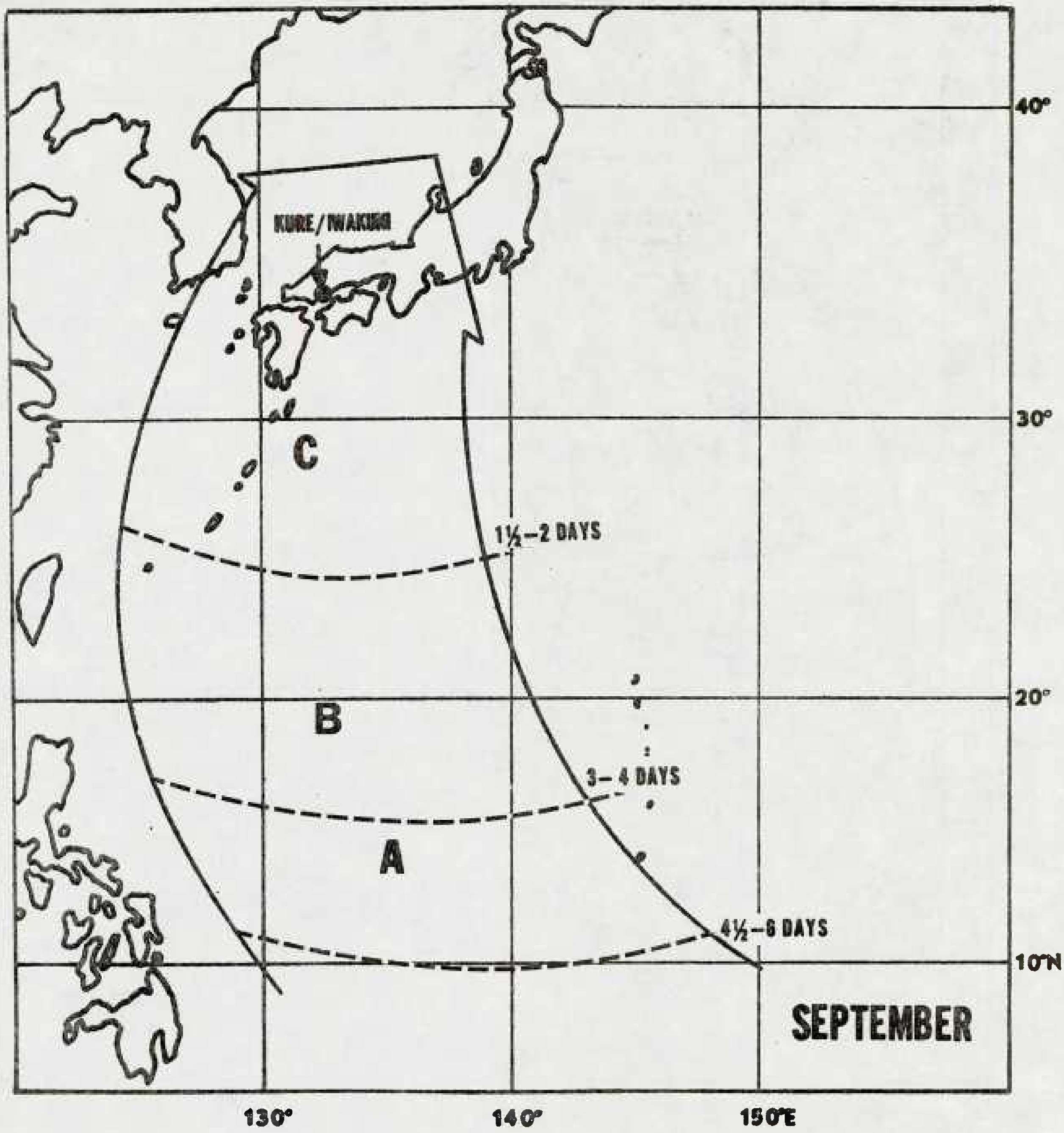

Figure 32. Tropical cyclone threat axis for the month of September. The area within the arrow approximates a 30% or greater probability of a tropical cyclone coming within 180 n mi of Iwakuni/Kure. Approach times are based on typical speeds of movement for tropical cyclones affecting Iwakuni/Kure.

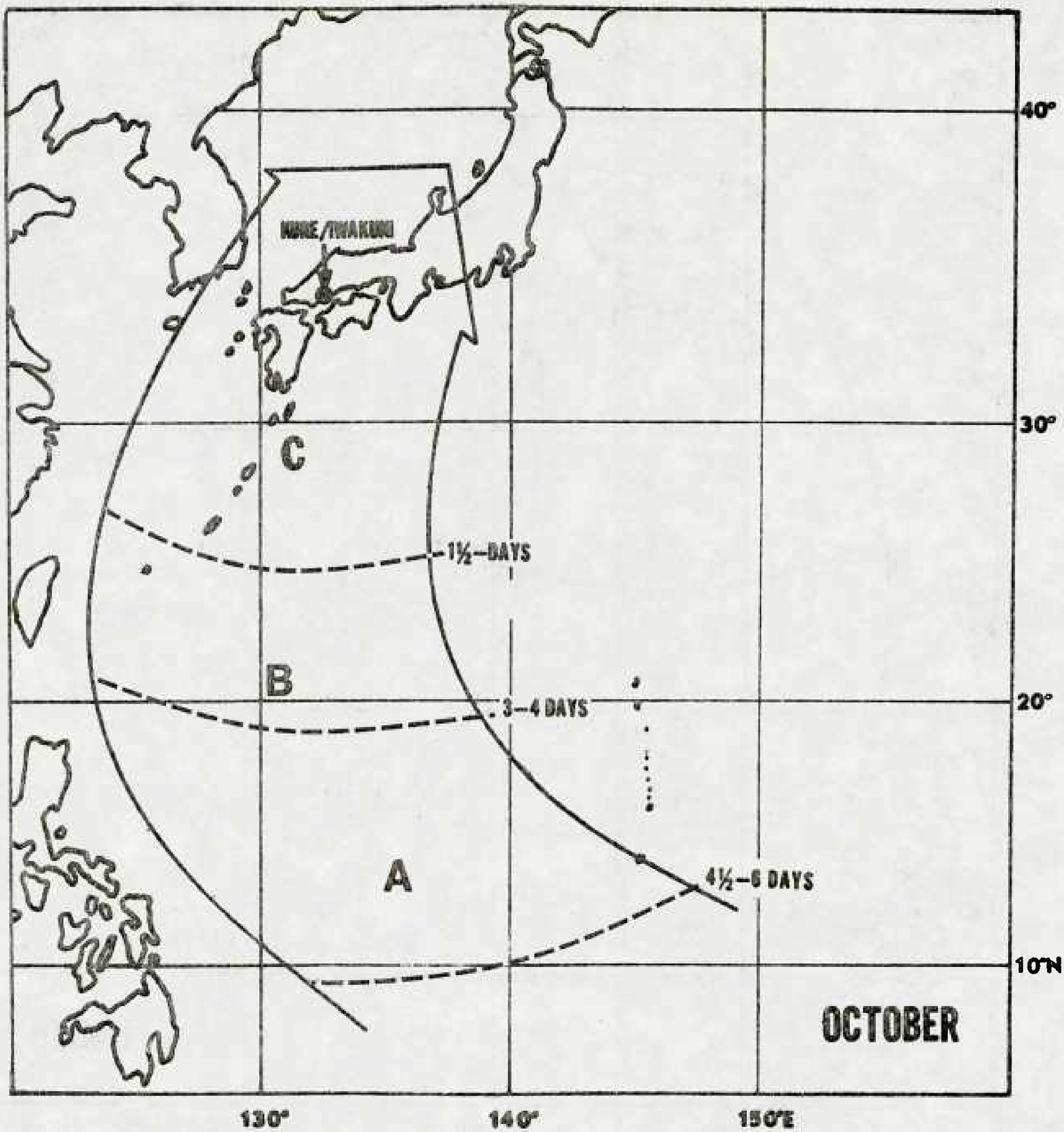

Figure 33. Tropical cyclone threat axis for the month of October. The area within the arrow approximates a 30% or greater probability of a tropical cyclone coming within 180 n mi of Iwakuni/Kure. Approach times are based on typical speeds of movement for tropical cyclones affecting Iwakuni/Kure.

b. All ships begin planning course of action to be taken if a shift in anchorage is anticipated.

III. Tropical cyclone enters area C of Figures 29-33 with forecast movement toward Iwakuni/Kure.

a. Execute plans made in step II with the aid of information in Sections 6.3 and 6.4 if the ship is in port at Iwakuni or Kure.

6.3 REMAINING IN PORT AT IWAKUNI/KURE

Remaining in port at Iwakuni (considering Areas A and C of Figure 8 as typhoon anchorages for Iwakuni) and Kure (considering Area D of Figures 8 and 10) is the recommended course of action for all ships. As stated in Section 4.2.2, Kure is considered to be one of the best, if not the best, typhoon haven in all of Japan (crowding, however, may be a consideration). As a consequence of conversations with Kure Harbor authorities, Area D of Figures 8 and 10 is recommended for large vessels, including supertankers and naval combatants. Smaller vessels normally remain pierside or utilize the protection found in the various coves found around the harbor.

For those ships in port Iwakuni the recommended procedure is to move to one of the designated typhoon anchorages, either Area A or C or D (in Kure) as seen in Figures 8 and 10.

Ship commanders should utilize the tropical cyclone warnings issued by FWC/JTWC, Guam in conjunction with Figures 29-33 to insure a timely shift to the typhoon anchorages. Ship commanders should also determine from the warnings whether the storm is forecast to pass west of Hiroshima Bay or east of the bay. Area A should provide excellent protection with storm passage to the west and very good coverage for storms passing to the south and east. Area C should provide excellent protection from storms which pass to the east.

6.4 EVASION AT SEA

Evasion at sea is not the recommended course of action. However, if it is desired an evasion route to sea may be developed by the use of the FWC/JTWC warnings, Appendix A and Figures 29-33 of this report. In all cases, however, Optimum Track Ship Routing (OTSR) should be consulted as to the best evasion route.

There are two basic evasion tactics for ships at sea south of Japan. The most common is to place the ship south of the tropical cyclone in the left or navigable semicircle. The other is to proceed southeast or east to remain clear of the tropical cyclones track.

If a ship is in the area south of Japan and the decision is made to seek refuge in Iwakuni or Kure, then the time enroute through the Bongo Straits into Hiroshima Bay (see Figure 7) should be considered. At speeds of 10-12 kt, an enroute time of 10-12 hours could be expected upon entering the Bongo Straits.

Another option for ships south of Japan desiring refuge in a port would be the consideration of Yokosuka, Japan -- a designated safe typhoon "haven."[3]

For a ship in the Sea of Japan or the Korean Straits, there are also two basic evasion tactics. The most common is to place the ship in the left or navigable semicircle of the tropical cyclone. The other is to proceed further north in the Sea of Japan or north into the Yellow sea.

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[3]See "An Evaluation of the Harbor of Yokosuka, Japan as a Typhoon Haven," ENVPREDRSCHFAC Tech. Paper No. 15-75.

In the latter case, the cooler surface water and cool air found at higher latitudes cause a weakening and ultimate dissipation of the tropical cyclone. The central winds of tropical cyclones north of 35N are generally below 64 kt. Therefore, a ship would experience less difficulty in riding out a storm at these latitudes than if it steamed south to seek the navigable semicircle and encountered winds in excess of 80 kt enroute.

If refuge in port is desired, Sasebo, Japan, a designated typhoon "haven"[4] would be more easily accessible to ships in the Sea of Japan or Korean Straits, than Iwakuni or Kure.

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[4]See "An Evaluation of Sasebo Harbor, Japan as a Typhoon Haven," ENVPREDRSCHFAC Tech. Paper No. 17-75.

7. CONCLUSIONS

The conclusions reached by this study are first that Kure Harbor is a favorable typhoon "haven" for all ships; second, Iwakuni Harbor, although not recommended as a "haven," has easily accessible anchorages closeby which are considered safe during typhoon passage. These conclusions are based on the following:

1. The location and topography of the entire Iwakuni/Kure area significantly reduces the effects of winds attending tropical cyclones.
2. Anchor holding in the designated anchorage areas is rated as excellent.
3. Surge effect is almost negligible and wave heights are not severe in the designated anchorage areas.
4. Port services and repair facilities at Kure (also available to ships at Iwakuni) are among the best in all of Japan.
5. Conversations with local harbor and meteorology officials.

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APPENDIX A

The mean typhoon tracks, track limits and average speed of movements for the month of June and in ten-day periods for July-October are depicted in Figures A-1 to A-13. It must be realized that storms deviate from the mean tracks, but about 80 percent will fall within the track limits. The use of these tracks should be of particular benefit in long range (in excess of 48 hours) planning. The application of average tracks to the short range specific situation should be avoided (U.S. FWF Sangley Point, 1967).

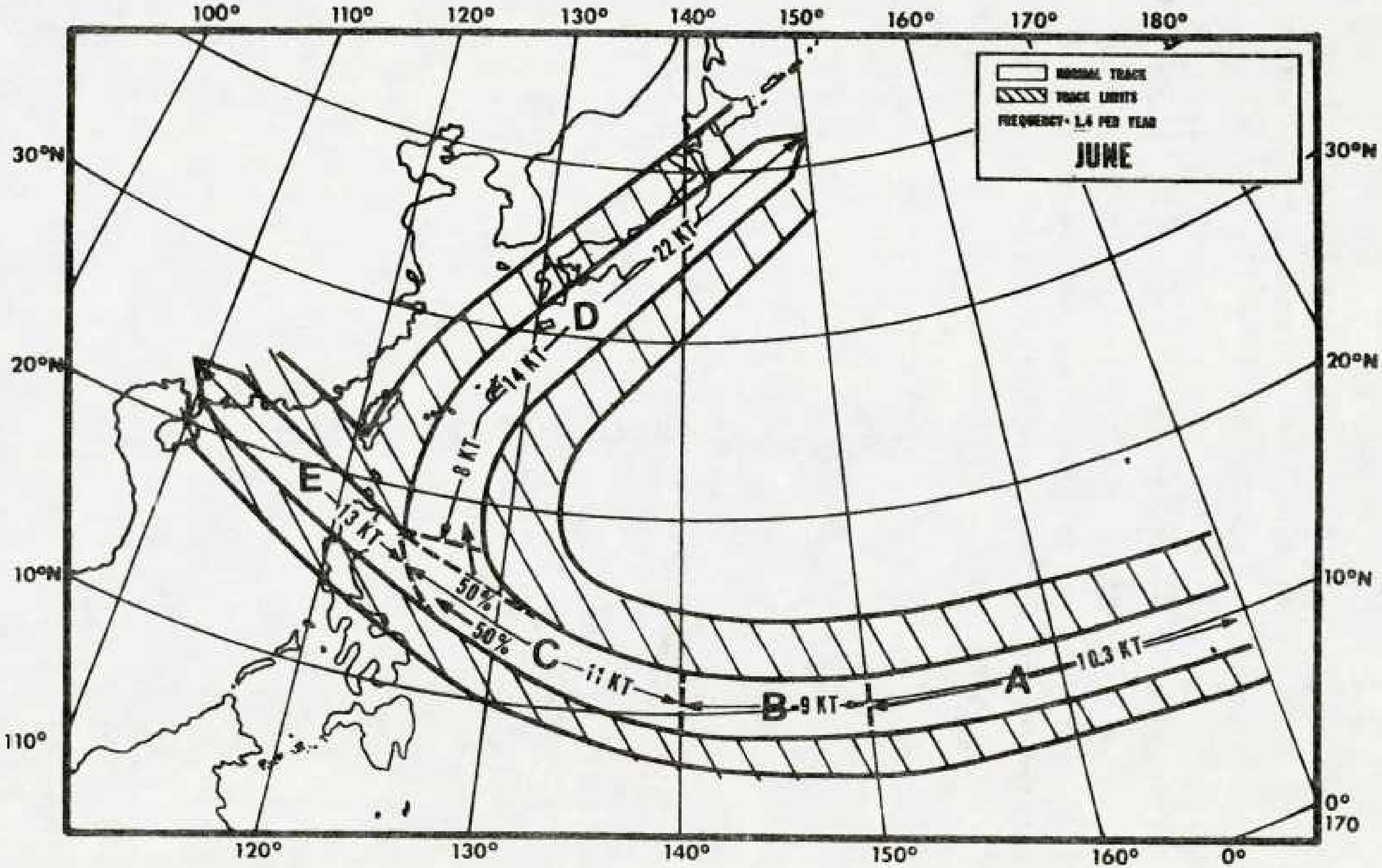


Figure A-1. Mean typhoon tracks for June. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

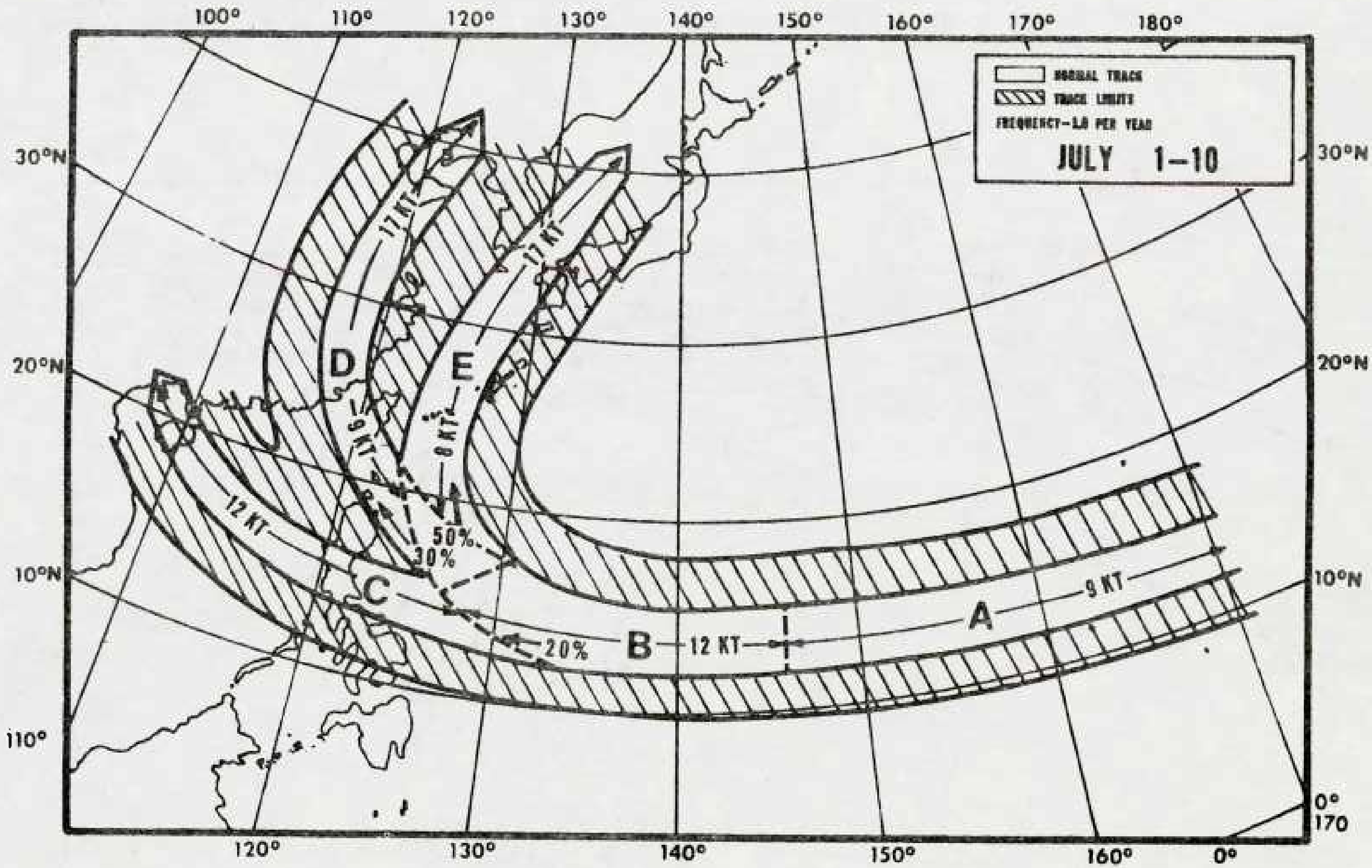


Figure A-2. Mean typhoon tracks for 1-10 July. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

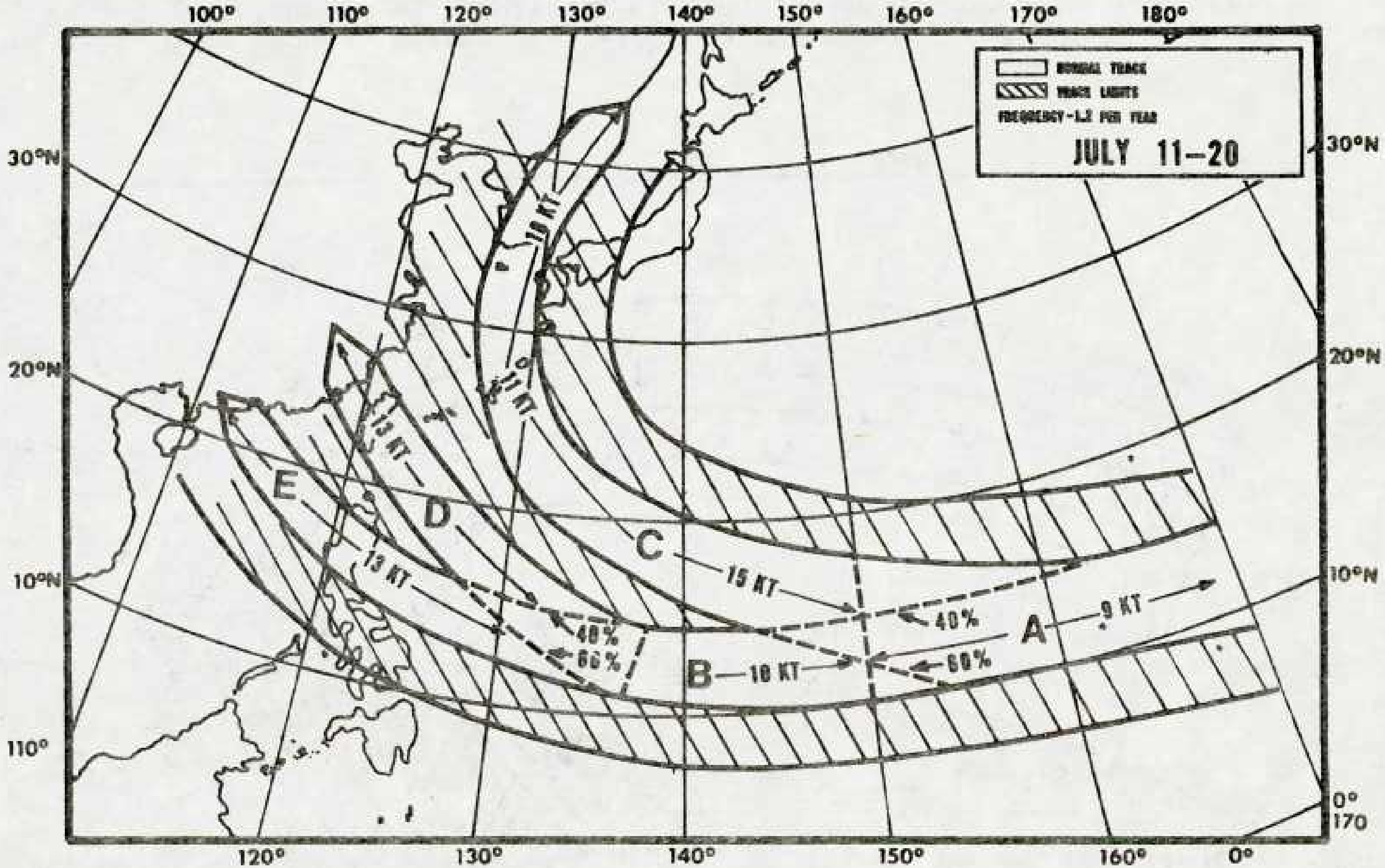


Figure A-3. Mean typhoon tracks for 11-20 July. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

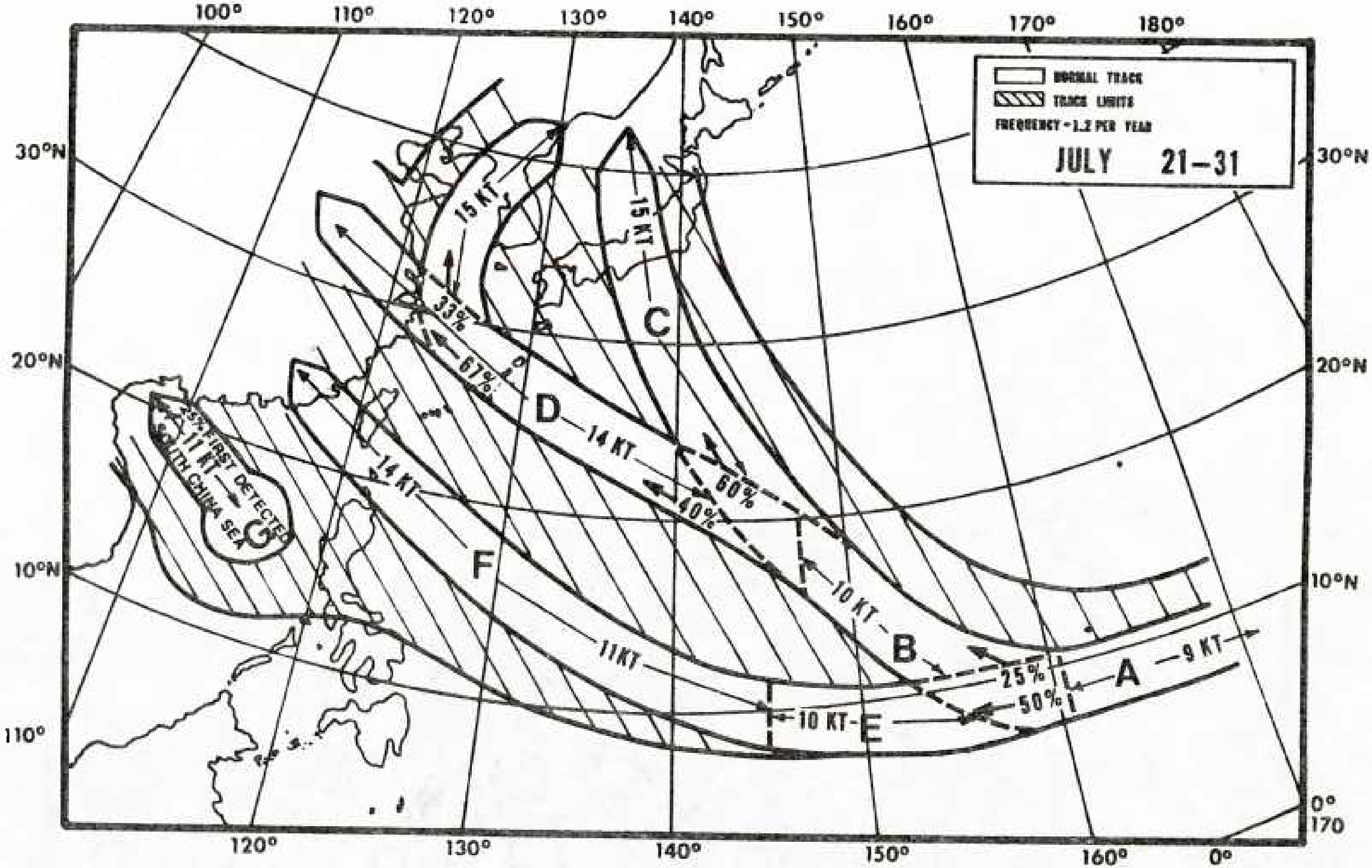


Figure A-4. Mean typhoon tracks for 21-31 July. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

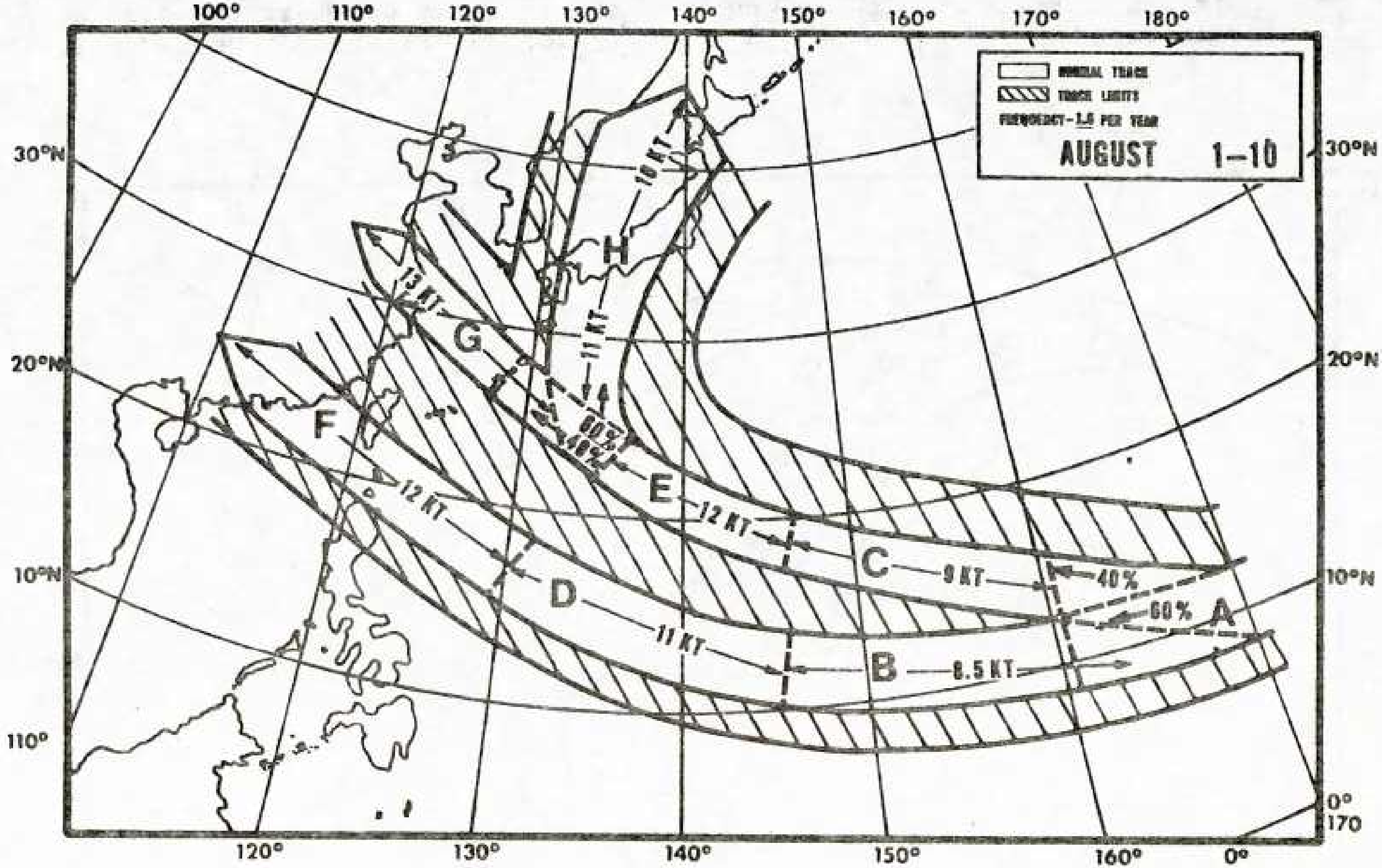


Figure A-5. Mean typhoon tracks for 1-10 August. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

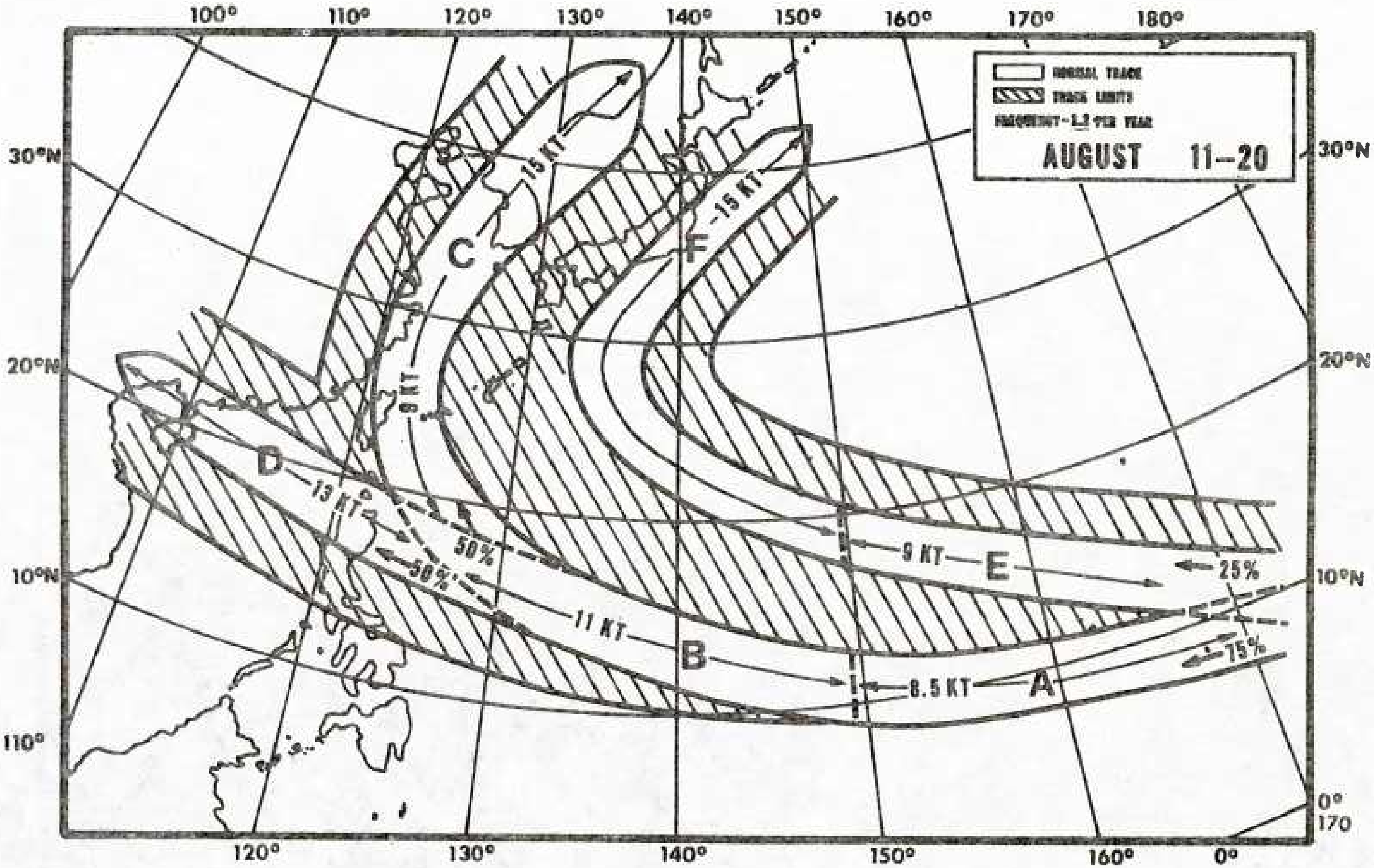


Figure A-6. Mean typhoon tracks for 11-20 August. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

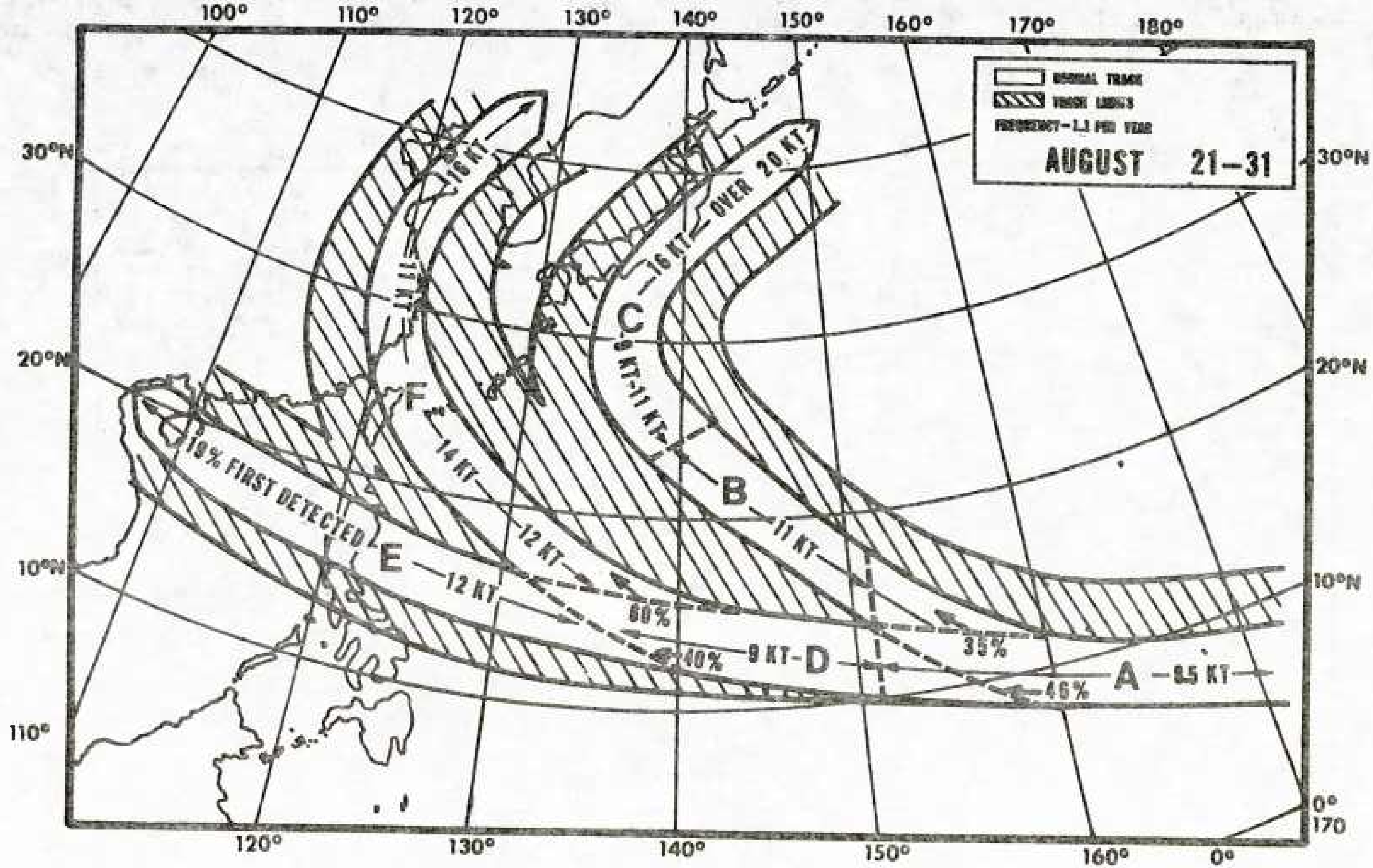


Figure A-7. Mean typhoon tracks for 21-31 August. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

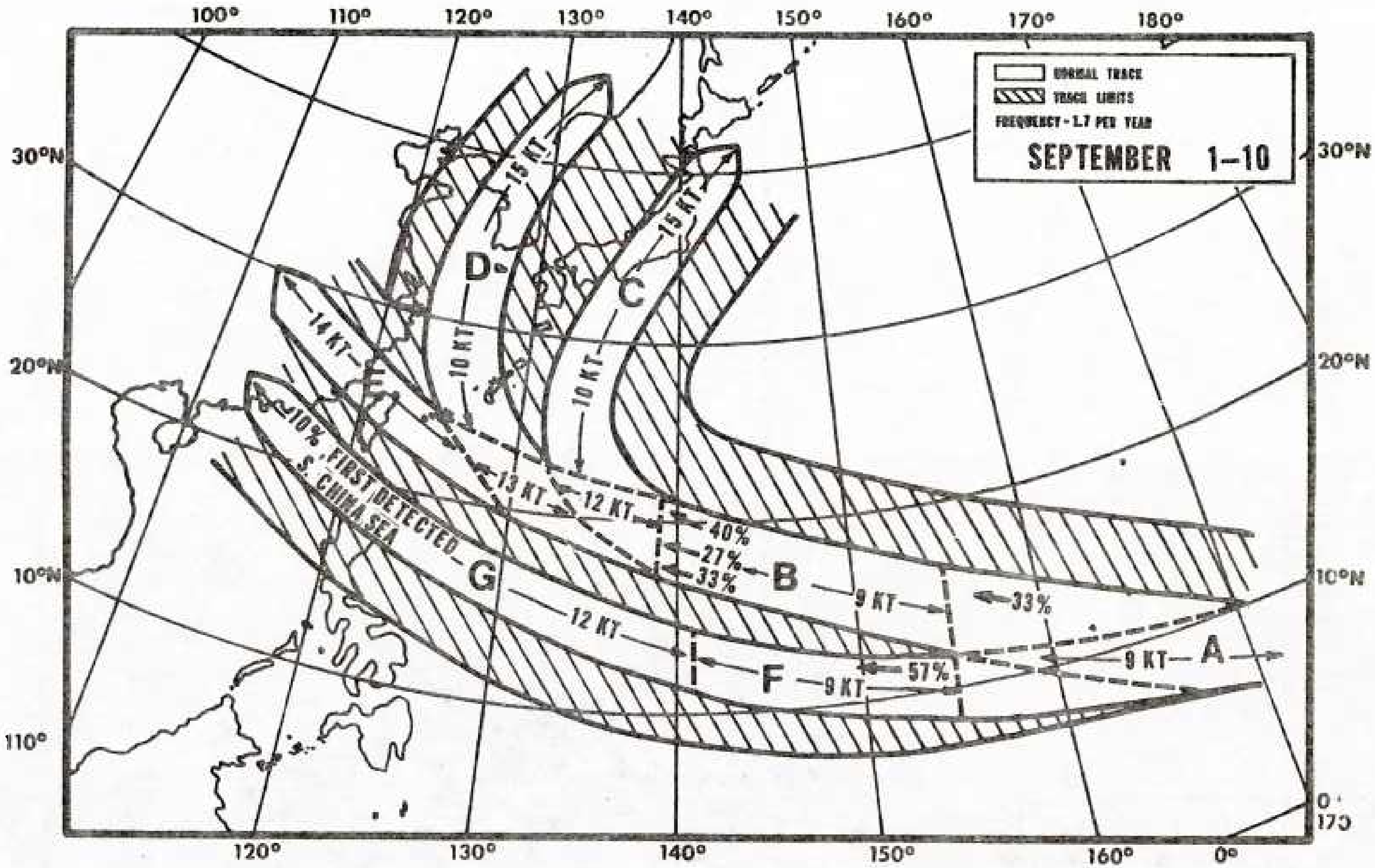


Figure A-8. Mean typhoon tracks for 1-10 September. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

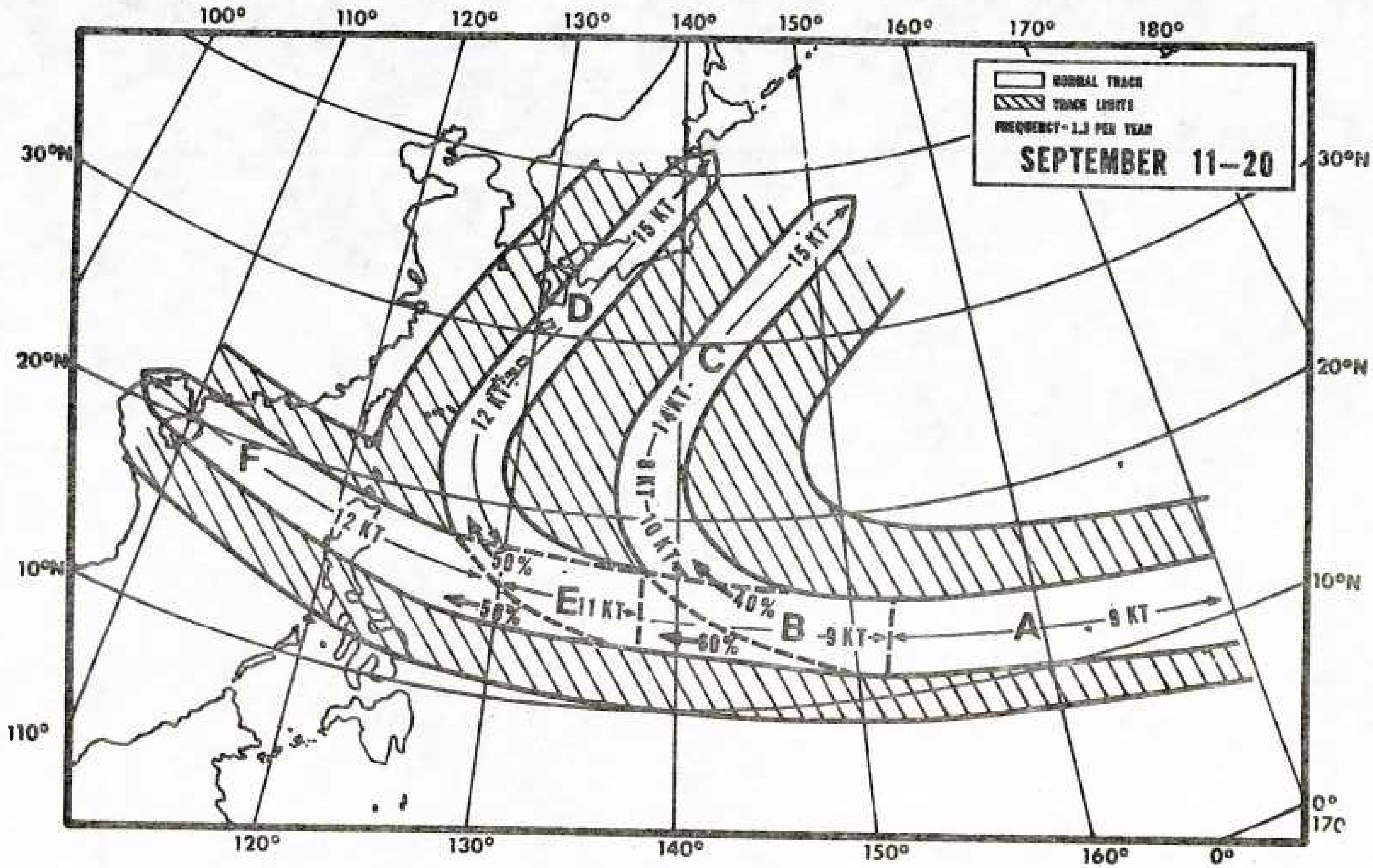


Figure A-9. Mean typhoon tracks for 11-20 September. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

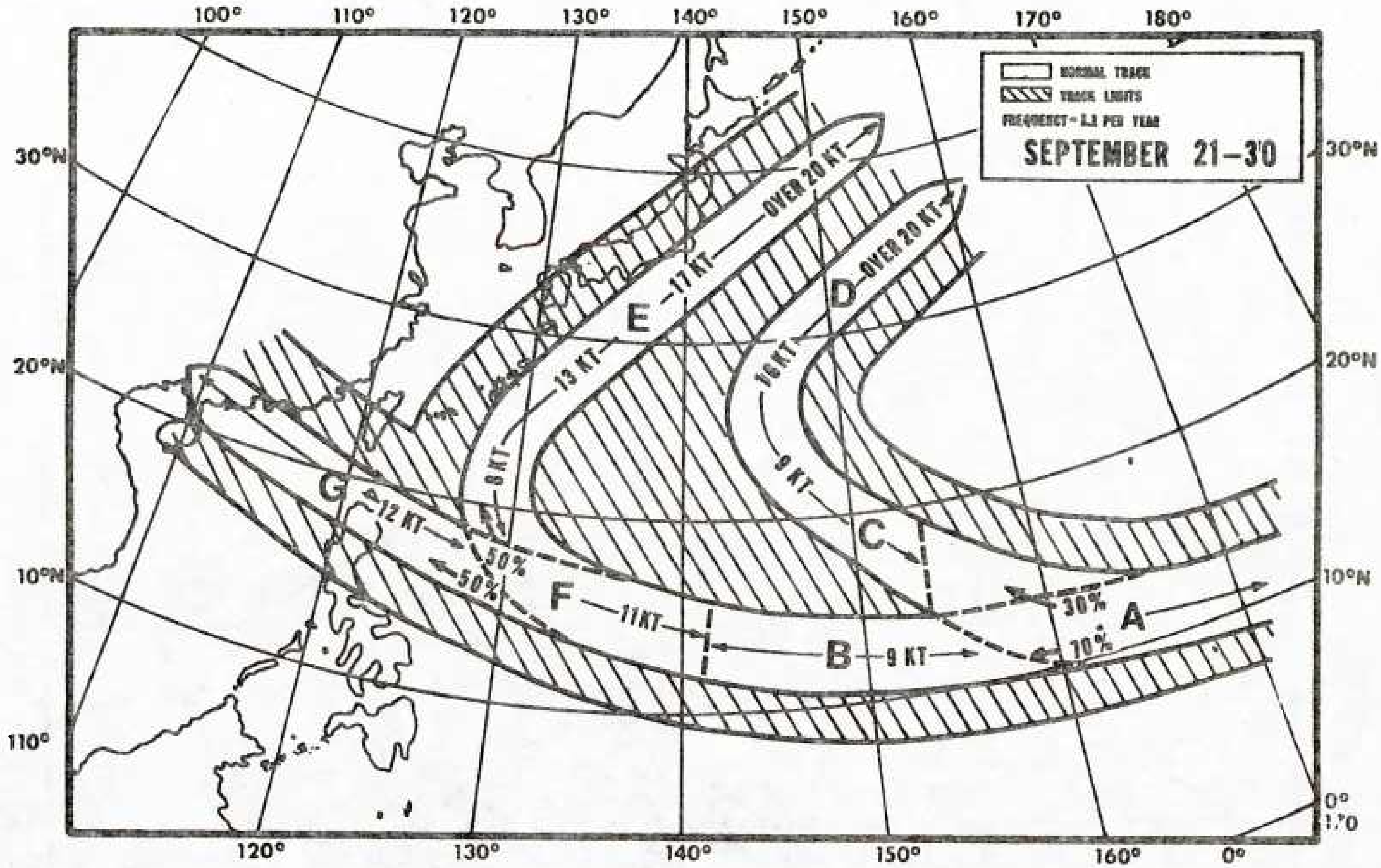


Figure A-10. Mean typhoon tracks for 21-30 September. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

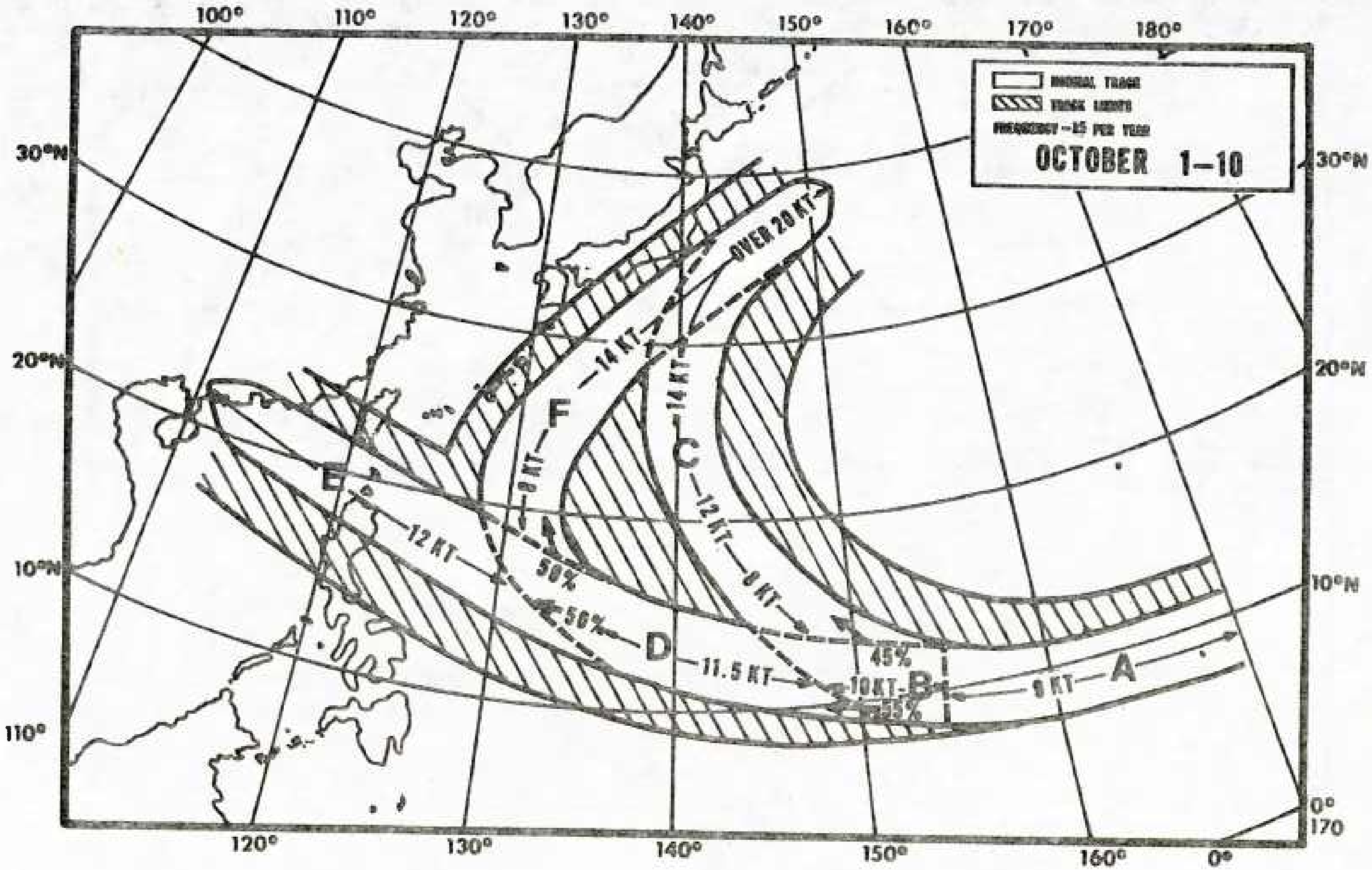


Figure A-11. Mean typhoon tracks for 1-10 October. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

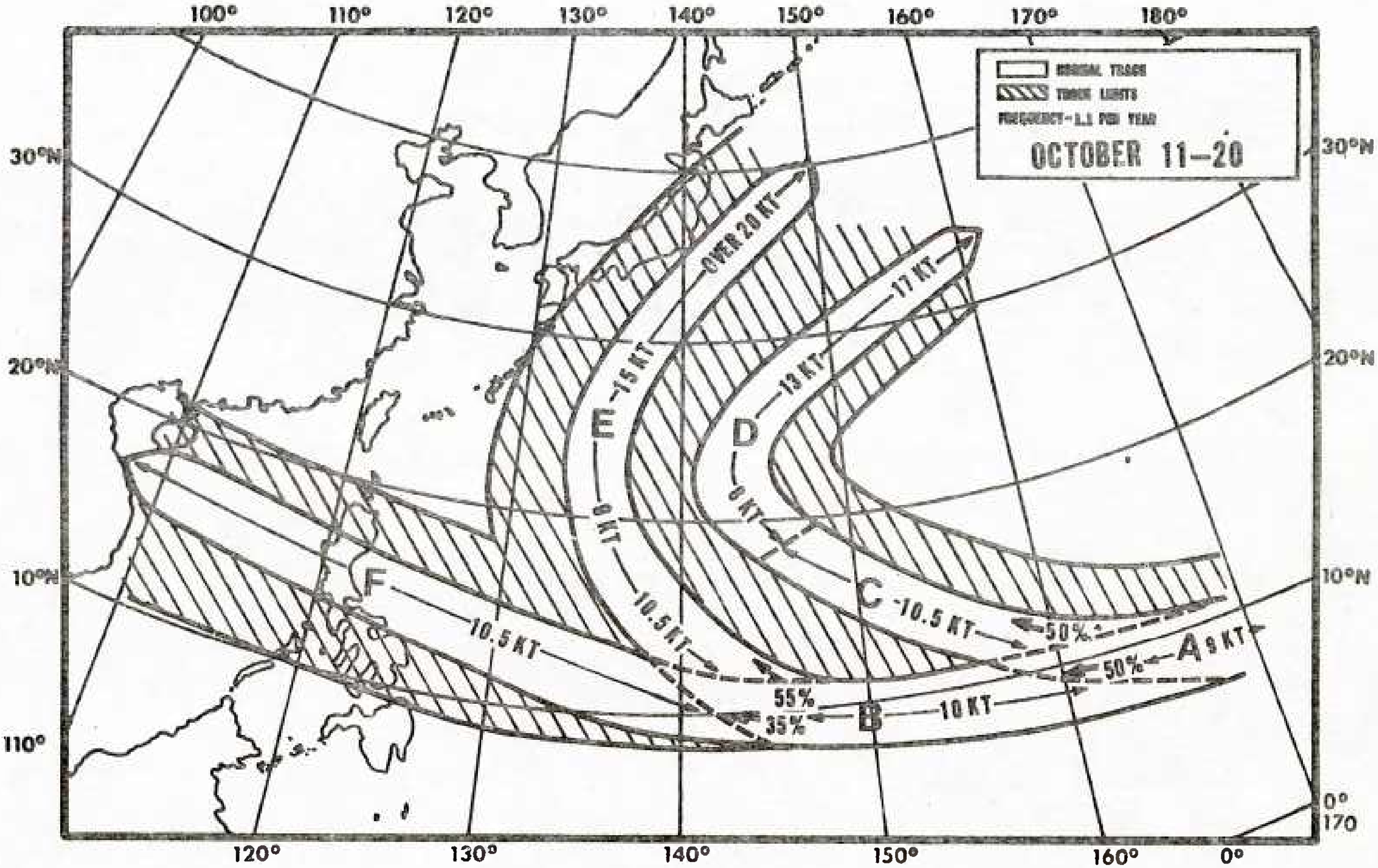


Figure A-12. Mean typhoon tracks for 11-20 October. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

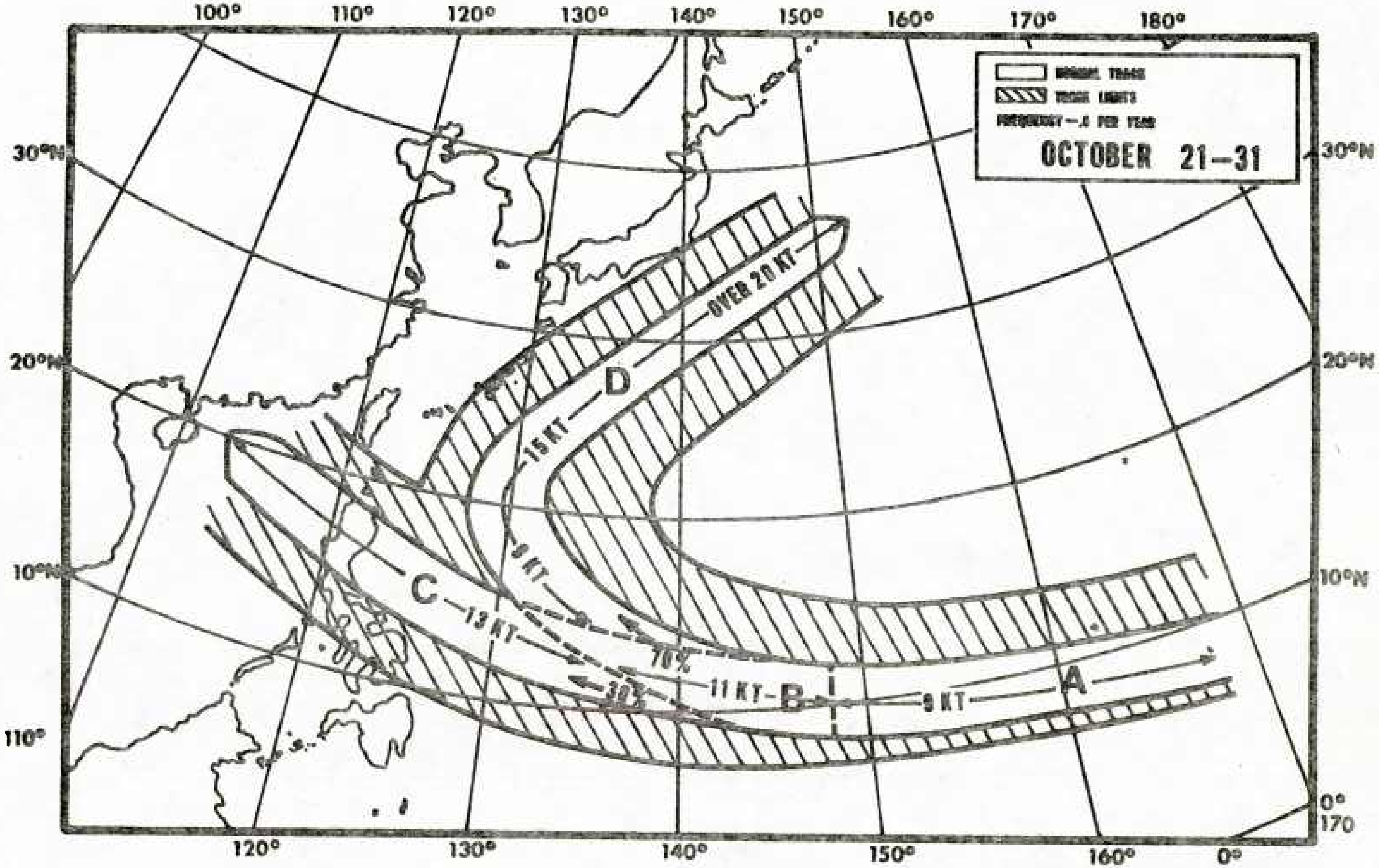


Figure A-13. Mean typhoon tracks for 21-31 October. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

APPENDIX B

CALCULATING THE "DANGER AREA"
(From CINCPACFLT OPORD 201-YR)

(2) Calculating Danger Area. Although forecast accuracy is improving, the average Joint Typhoon Warning Center 24 hour typhoon forecast error, derived from statistics over past years, is about 135 miles. Tropical cyclone warnings issued by the Joint Typhoon Warning Center, Guam, now contain 24 hour forecasts of peripheral winds greater than 50 knots and greater than 30 knots winds associated with a tropical cyclone. Should conditions of fetch and duration obtain, 30 knot winds are capable of producing a fully arisen sea with waves up to 28 feet. The nonexactness of center position reports and the fact that a typhoon often follows an erratic track have led to the evolution of rules for avoiding the destructive winds (greater than 30 knots) in the typhoon circulation. Figure 1 is one scheme for avoiding the winds and seas associated with typhoons.

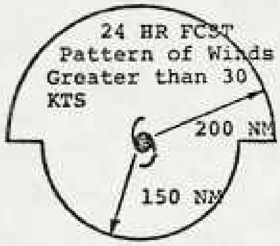


Figure 2

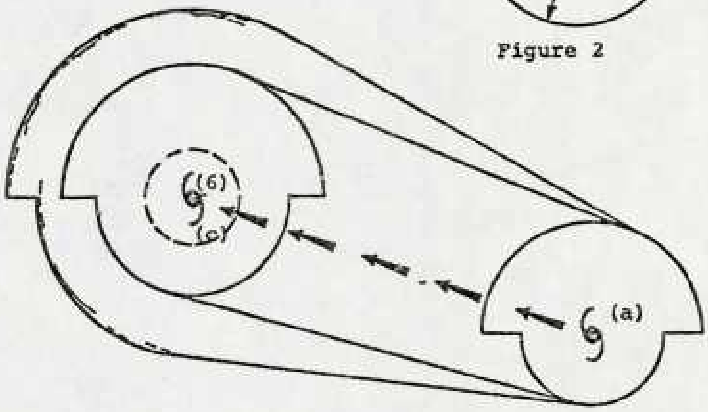


Figure 1

As each new warning is received:

(a) Mark the reported center position of the tropical cylone.

(b) Mark the 24 hour forecast center position of the cyclone.

(c) Draw a line from point (a) to point (b) indicating the forecast track.

(d) Using a radius of 135 miles draw a circle around the forecast center. This will enclose a locus area of possible 24 hour center positions.

(e) Extract the 24 hour forecast for winds greater than 30 knots. For example this might read, "RADIUS OF OVER 30 KT WIND: 24HRS VALID 021700Z 200 NM NORTH SEMICIRCLE 150 NM SOUTH SEMICIRCLE."

(f) Using a template or mechanical drawing compass lay off the locus of the limiting area of 24 hour forecast of winds greater than 30 knots (Fig. 2) by placing the center of the south oriented wind pattern along the perimeter of the 24 hour locus of possible center locations. A practical approximation would be simply to add 135 miles to the forecasted wind radii.

(g) Draw the envelope connecting the points of maximum extent of the 30 knot winds. The resultant enclosed area could very likely contain winds in excess of 30 knots within the next 24 hours. THE ENTIRE AREA IS TO BE AVOIDED.

(h) RECALCULATE THE DANGER AREA WITH EACH NEW WARNING RECEIVED

(3) Estimating Danger Area.

(a) Locating the ship relative to the dangerous and navigable semicircles to initiate evasion procedures is a continuing problem. Revision and updating of the typhoon's forecast movement may completely change the spatial relationship of ship to typhoon center. When still well in advance of the typhoon circulation, carefully plotting each new warning, ships should maneuver to avoid adverse winds and seas. However, changing course and speed to cross the forecast track of a typhoon in order to reach the navigable semicircle (TAB C) is considered extremely dangerous once the ship is located within the area of greater than 30 knots winds associated with the typhoon.

(b) In event that the center position of a typhoon is not available, the direction can be estimated as follows: "Face the wind. The bearing of the storm center is then 100 to 130 degrees to your right." Care should be taken not to use a wind direction during a squall, for the wind may be non-representative. Larger allowance in degrees should be made in the rear of a typhoon than in the front.

(c) A ship equipped with radar which is capable of giving a return from precipitation may be able to use it to advantage if near the storm. Attenuation of the signal by precipitation may cause the scope picture to be deceptive. For this reason the established methods of maneuvering in the vicinity of a typhoon must not be ignored.

e. Riding Out a Typhoon. When impossible to avoid the typhoon associated 30 knot winds standard rules serve as a guide. These depend on the ship's estimated position with relation to the track of the typhoon. Position with respect to the typhoon circulation depicted ideally in Tab C can be estimated by plotting the ship's position with respect to the forecast track and danger area depicted in figure 1.

(1) When on Track of Typhoon. If the barometer continues to fall and the wind direction remains constant or veers clockwise slowly and increase in intensity, the ship is on or near the track of the typhoon. In this case, bring the wind to the starboard quarter, note the course, hold it and run for the "navigable" semicircle. As long as the wind direction remains constant or veers slowly, the ship is in the path of the storm. When the wind has backed, or shifted counterclockwise, 15 degrees, the ship is entering the "navigable" semicircle.

(2) When in Dangerous Semicircle. If the ship is in the dangerous semicircle, bring the wind on the starboard bow and hold it there. Make as much way as the condition of the sea will allow. While maintaining this course, watch the wind log carefully. If the wind veers (clock-wise), it indicates that you are in the dangerous semicircle, so keep changing the course to hold the wind on the starboard bow, and the typhoon will pass astern.

(3) When in the "Navigable" Semicircle. If it is estimated that the ship is in the "navigable" semicircle, bring the wind on the starboard quarter, note the course, and hold it. If the wind backs (counter-clockwise) it means that the ship is in "navigable" semicircle. If this course is held, the typhoon will pass astern. However, if the wind starts to veer (clock-wise) it means that you are in dangerous semicircle rather than the "navigale" semicircle, and the course should be changed to follow the procedure described in subparagraph (2) above.

APPENDIX C

SHIPS SPEED VS WIND AND SEA STATE CHARTS

Figures C-1(a) and C-1(b) represent the estimated resultant speed-of-advance of a ship in a given sea condition. The original relationships were based on data of speed versus sea state obtained from studies of many ships by James, 1957. They should not be regarded as truly representative of any particular ship (Nagle, 1972).

For example, from Figure C-1(a), for a ship making 15 kt encountering waves of 16 ft approaching 030° (relative to the ship's heading) one can expect the speed-of-advance to be slowed to about 9 kt. Twenty foot seas, under the same condition, would result in a speed-of-advance of slightly less than 6 kt. However, it is emphasized that these figures are averages and the true values will vary slightly from ship to ship.

Figure C-2 shows the engine speed required to offset selected wind velocities for various ship types (computed for normal loading conditions).

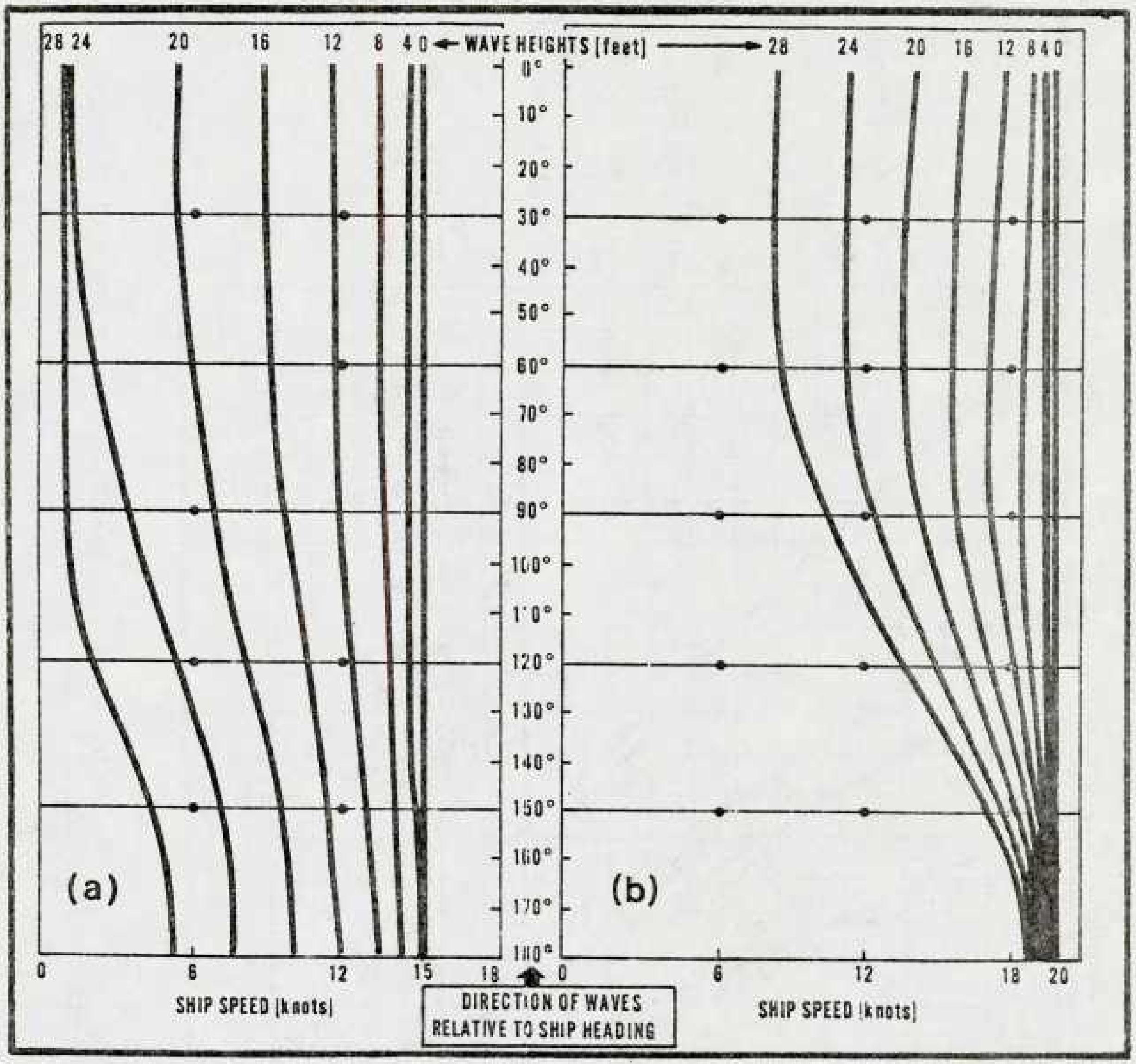
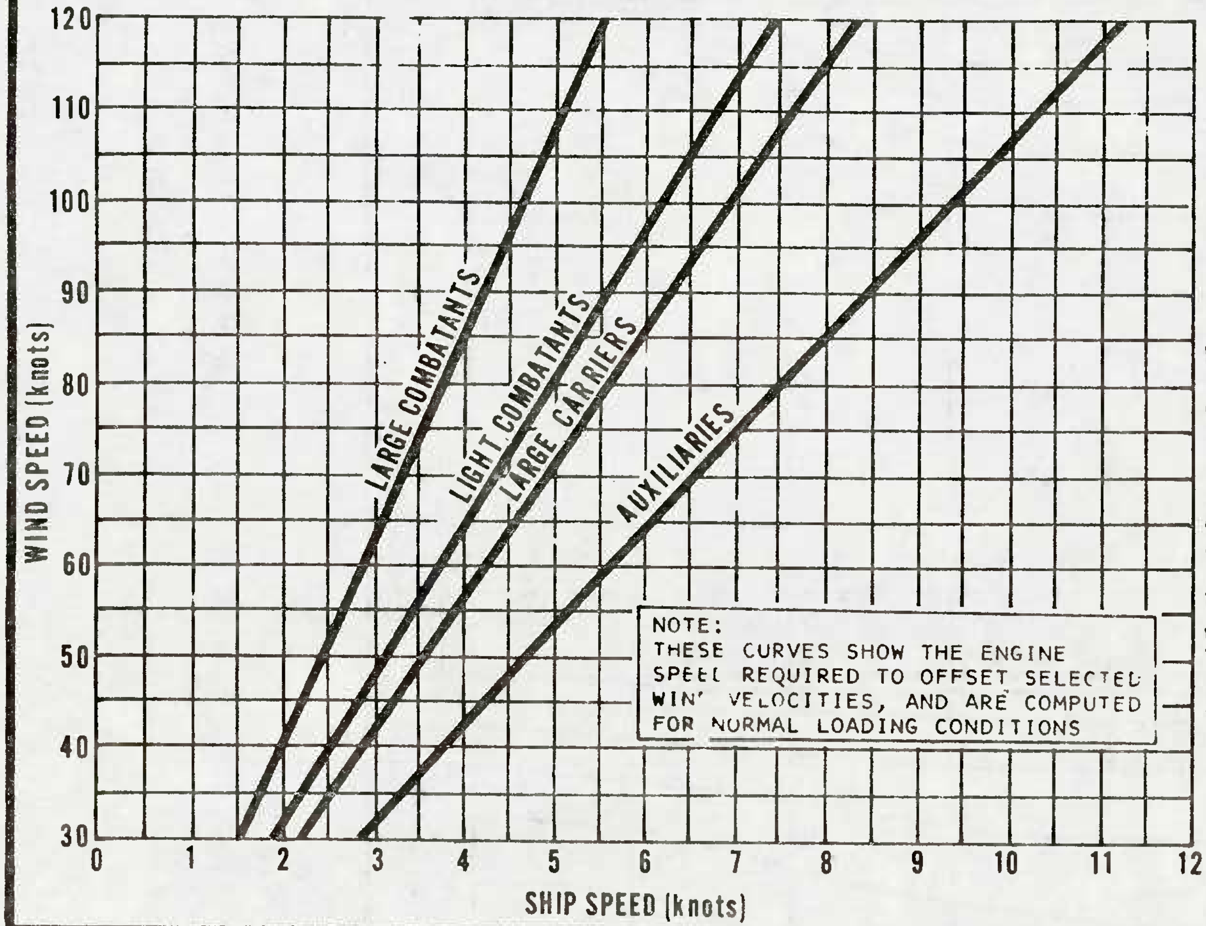


Figure C-1. Expected ship speed as a function of wave height and wave direction relative to ship's heading for (a) a ship making 15 kt and (b) a ship making 20 kt (from Nagle, 1972).



The curves shown were developed using the basic formula:

$$\text{WIND LOAD} = R_w A V^2$$

where R_w is equal to wind friction factor. (R_w is generally taken as 0.004.)

V is equal to wind velocity in knots

A is equal to projected area above the waterline in sq ft.

Three sets of calculations with varying R_w were used. The plotted values illustrated represent the mean of these values.

Figure C-2. Engine speed vs wind velocity for offsetting force of wind (from Crenshaw, 1965).